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OFFICE OF MANNED SPACE FLIGHT

APOLLO PROGRAM

STRUCTURAL SYSTEMS AND PROGRAM DECISIONS

Volume 2

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Prepared by
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NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Washington, D.C. 20546

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FOREWORD

This document, though an official release of the Apollo Program Office, is furnished for information purposes only. Its purpose is to create awareness, stimulate interest and further promote understanding in the art and science of making real-life forecasts and their subsequent utilization in the control of space vehicle weight and performance throughout the Apollo Program.

This book is primarily intended for those in the Apollo Program who are responsible for the administration, design, development, manufacture, and test of the Apollo System. New theorems have been developed, as well as application of proven techniques but more importantly, a weight/performance forecasting methodology has been developed and automated. The text emphasizes the utilization of forecasting devices as applied to space vehicle weight and performance since these two parameters are of vital interest to all levels of management as well as technical personnel. Further, weight is tangible and readily measurable and can be readily related to performance.

The text provides, to those who wish to apply the developed methodology, all details necessary to do so and includes the mathematical development, computer program user's manuals and necessary instructions and procedures.

Forecasts and Appraisals for Management Evaluation text is intended to be a constructive aid to the NASA Apollo team in assisting them in the weight and performance area.

Samuel C. Phillips
Major General, USAF
Director, Apollo Program

TABLE OF CONTENTS

TABLE OF CONTENTS (Cont.)

TABLE OF CONTENTS (Cont.)

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (Cont.)

LIST OF ILLUSTRATIONS (Cont.)

LIST OF TABLES

SECTION 1

INTRODUCTION

1.1 PURPOSE

The purpose of Volume II of the Structural Systems and Program Decisions document is to present a detailed description of the programming of the Structural Weight Optimization Program (SWOP) under executive control. Individual subprograms related to SWOP are also described in detail.

1.2 CONTENTS

A general description of the SWOP program and its various subprograms is contained in Volume 1, The User's Manual. Engineering analyses for the optimization of these subprograms are found in the appendices to Volume 1.

Volume II, therefore, supplements these general descriptions with more detailed programming information. Details of mathematical techniques such as iterations used in the procedures for optimizing each construction and instructions for corrective measures are provided.

Section 2 details the organization and description of the Executive Control Program. The STRESS subprogram is covered in Section 3 and the construction subprograms are found in Section 4. These are followed by the subroutines developed for the single-face corrugation, semi-monocoque and the integral ring and stringer stiffened construction subprograms. Each section contains flow charts which can be used for planning purposes to provide expansions and additions to the program which is highly modular in design.

SECTION 2

EXECUTIVE CONTROL PROGRAM

2.1 ORGANIZATION

The executive control program consists of a main controlling program, and a series of modules. Each module is designed to perform a particular task. The main program guides the flow of control through the necessary modules as it decides which sequence of operations is required to perform the user-specified task. A listing of available options, and a discussion of the executive control program philosophy and the advantages of executive control program organization is given in Section 4 and Appendix D of the User's Manual. This section is concerned primarily with the programming details.

A flow chart showing the hookup of modules is illustrated in Figure 2-1. These modules can be altered to fit the overlay scheme at the user's computer facility.

2.2 DESCRIPTION

The following variables are used in the executive control program.

2.2.1 COMMON/MATPRO/PROP (12, 16), TPROP (12, 5, 10) EC, SY, SU, SI0, SI85, TEMP

This common block is used for storing material properties. The array PROP (12, 16) contains material properties according to the following code.

2.2.1.1 PROP (I, J)

PROP (I, J) = the actual property, where:

a. I = metal index (1 to 12). Present configuration is:

1 ⇒	Aluminum	2014-T6
2 ⇒	Aluminum	7075-T6
3 ⇒	Aluminum	2024-T4
4 ⇒	Aluminum	2219-T87
5 ⇒	Titanium	6A1-4V
6 ⇒	Steel	AISI4340
7 ⇒	Magnesium	HK 31A-H24

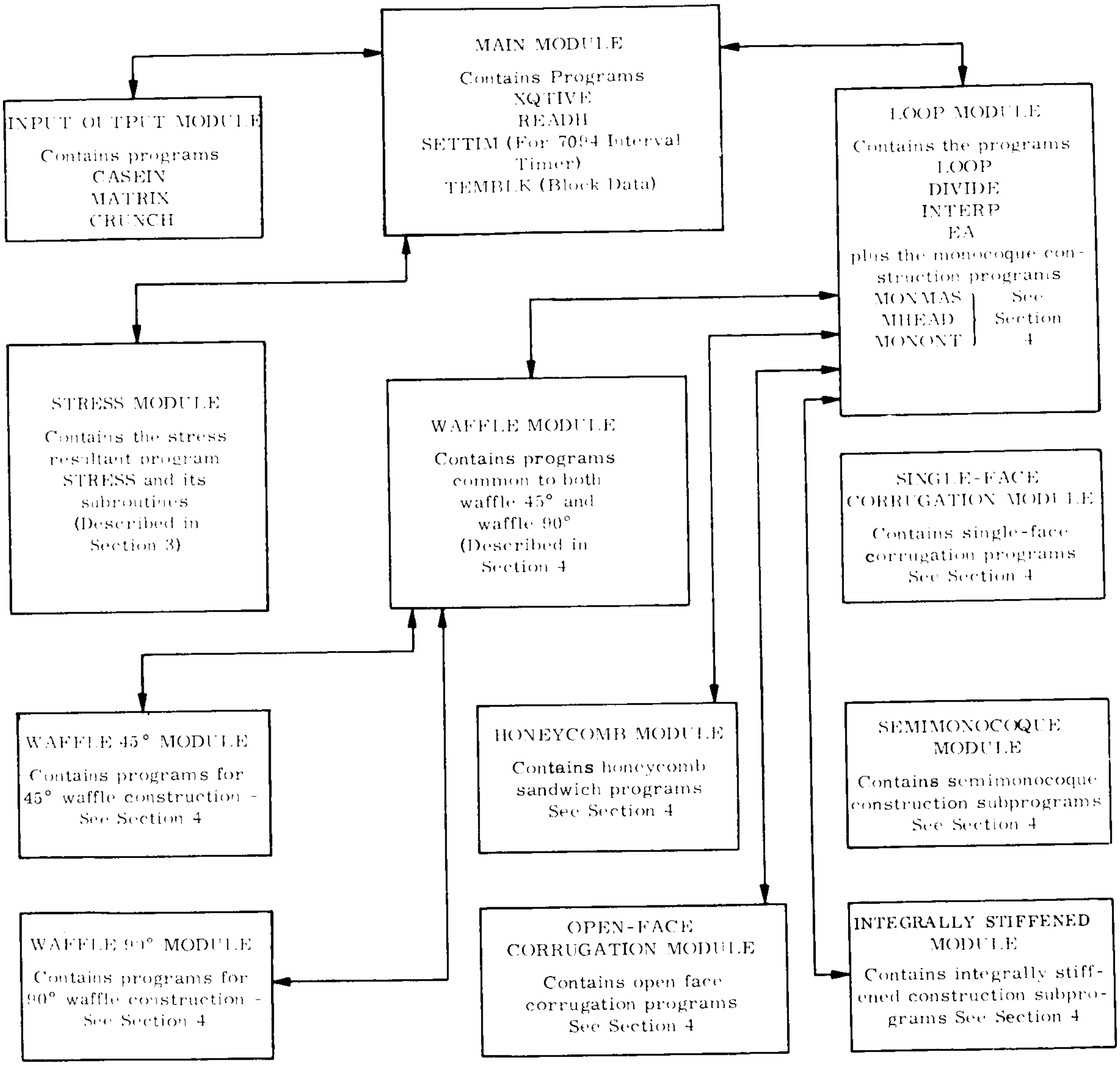


Figure 2-1. Flow Chart of Module Hookup

8 ⇒ Stainless Steel PH15-17M0

9 ⇒ Berylium Y5804-QMV5

10, 11, 12 } blanks left for expansion

b. J = property index, where:

1 ⇒ material density

2 ⇒ Poisson's ratio for material

3 ⇒ monocoque minimum skin thickness

4 ⇒ honeycomb minimum face thickness

5 ⇒ waffle minimum rib thickness

6 ⇒ waffle minimum skin thickness

7 ⇒ corrugation minimum skin thickness

8 ⇒ corrugation minimum corrugation thickness

9 ⇒ corrugation minimum ring thickness

10 ⇒ semi-monocoque minimum skin thickness

11 ⇒ integral stiffened minimum skin thickness

12 ⇒ integral stiffened minimum stringer thickness

13, 14, 15, 16 } blanks left for future expansion

2.2.1.2 TPROP (I, J, K)

TPROP (I, J, K) = the material property with:

a. I = metal index (1 to 12), as for 2.2.1.1.

b. J = property index (1 to 5), where:

1 ⇒ E_c, the Young's modulus

2 ⇒ σ_y, the yield stress

3 ⇒ σ_{ult}, the ultimate stress

4 ⇒ σ_o, the secant yield stress at 70 percent E_c

5 ⇒ σ_{85}, the secant yield stress at 85 percent E_c

c. K = the index of the temperature (1 to 10) at which the material property is given. Presently, K = 1 to 9 is used, with temperatures of +100 degrees to -300 degrees covered in increments of 50 degrees.

2.2.1.3 $\underline{E_c}$

E_c = Young's modulus returned by subroutine INTERP for temperature given in TEMP.

2.2.1.4 SY

SY = yield stress of material returned by INTERP.

2.2.1.5 SU

SU = ultimate stress returned by INTERP.

2.2.1.6 SI0

SI0 = secant modulus at 70 percent of E_c returned by INTERP.

2.2.1.7 SI85

SI85 = secant modulus at 85 percent of E_c returned by INTERP.

2.2.1.8 TEMP

TEMP = temperature input to INTERP routine for finding of material properties.

2.2.2 COMMON/USES/NSUS (6), NMUS (7)

2.2.2.1 NSUS (1)

NSUS (1) = the total number of subprograms to be entered into the matrix leaders.

2.2.2.2 NSUS (2 to 6)

NSUS (2 to 6) = the actual subprogram indices for this matrix (up to a total of 5) (see below).

2.2.2.3 NMUS (1)

NMUS (1) = the total number of materials to be entered into the matrix leaders.

2 2.2.4 NMUS (2 to 7)

NMUS (2 to 7) = the actual material indices for this matrix (up to a total of 6).

Subprogram indices follow the code:

1 ⇒ monocoque

2 ⇒ honeycomb sandwich

3 ⇒ 45-degree waffle

4 ⇒ 90-degree waffle

5 ⇒ no-face corrugation

6 ⇒ single-face corrugation

7 ⇒ semi-monocoque

8 ⇒ integral ring and stringer stiffened

9, 10 } blanks left for expansion

2.2.3 COMMON/LOOPER/NSP (10, 8)

2.2.3.1 NSP (I, 1)

NSP (I, 1) = signal for whether subprogram I is to be included in the present loop.

NSP (I, 1) = 2 ⇒ signal is "on."

NSP (I, 1) = 0 ⇒ signal is "off."

2.2.3.2 NSP (I, 2)

NSP (I, 2) = total number of materials to be included in the loop for construction subprogram I (up to 6 materials).

2.2.3.3 NSP (I, 3) to NSP (I, 8)

NSP (I, 3) to NSP (I, 8) = the actual indices of the materials to be run with subprogram I.

2.2.4 COMMON/IDBLOK/ID (50, 2), ICOUNT, ITSP, ITMAT

2.2.4.1 ID (I, 1)

ID (I, 1) = discontinuity at which the "I^{th}" structural unit being considered in this job is located. For heads, this is the discontinuity at which it is attached to the wall of the vehicle. For conical sections, this is the discontinuity at the bottom of the station.

2.2.4.2 ID (I, 2)

ID (I, 2) = a signal which indicates the type of the "I^{th}" structural unit in this job.

ID (I, 2) = 1 ⇒ conical section
= 2 ⇒ bottom head
= 3 ⇒ top head

2.2.4.3 ICOUNT

ICOUNT = the number indicating the sequence in this job of the structural unit presently under consideration. For example, ICOUNT = 5 indicates that we are presently optimizing the fifth structural section in this job.

2.2.4.4 ITSP

ITSP = index of construction subprogram presently under consideration.

2.2.4.5 ITMAT

ITMAT = index of material presently under consideration.

2.2.5 COMMON/BLURB1/LRUN, LPHASE, NTANKS, DH, G1, G2, HP (10), HD (10), STIME, ETIME, KHYDRO, XMEMBR

This is a labeled common into which run and phase headers are read from the STRESS restart tape. The variables presently used by the executive control program from this common are as follows.

2.2.5.1 LRUN

LRUN = run number.

2.2.5.2 LPHASE

LPHASE = phase number.

2.2.5.3 NTANKS

NTANKS = number of tanks.

2.2.5.4 HP (I)

HP (1) = effective pressure of tank I.

2.2.5.5 HD (I)

HD (I) = test fluid density for tank I.

2.2.5.6 STIME

STIME = time of start of flight.

2.2.5.7 ETIME

ETIME = time of end of flight.

2.2.5.8 KHYDRO

KHYDRO = signal for hydrostatic test.

2.2.5.9 KMEMBR

KMEMBR = (Not used in this version of the program)

2.2.6 COMMON/BLURB2/NTB, NTY, IMET, A, B, C, NAIL, ITAN, VSUB

This is a labeled common into which information for each structural section is read. The following variables are used by the executive control program and its subprograms.

2.2.6.1 NTB

NTB = number of stations considered for this structural section.

2.2.6.2 NTY

NTY = signal indicating type of this structural section.

NTY = - 1 ⇒ conical section
= 0 ⇒ bottom head
= + 1 ⇒ top head

2.2.6.3 A

A = semimajor axis, if this is an ellipsoidal head.

2.2.6.4 B

B = semiminor axis, if this is an ellipsoidal head.

2.2.6.5 C

C – height of this ellipsoidal head.

2.2.6.6 NAIL

NAIL = discontinuity for this structural unit.

2.2.6.7 VSUB (Not used in this version of the program)

2.2.6.8 ITAN (Not used in this version of the program)

2.2.7 COMMON/TSTORE/UPD (400, 17)

2.2.7.1 UPD (I, J)

UPD (I, J) = information about each station for this structural unit, where I = station number (I may assume values from 1 to NTB).

2.2.7.2 UPD (I, 1)

UPD (I, 1) = height at station I.

2.2.7.3 UPD (I, 2)

UPD (I, 2) = N_x, the axial stress for maximum membrane load (picked over time) at this station. "+" sign indicates tension. "-" sign indicates compression.

2.2.7.4 UPD (I, 3)

UPD (I, 3) = N_y, the hoop stress for maximum membrane load at this station.

2.2.7.5 UPD (I, 4)

UPD (I, 4) = radius at station I. A negative sign is given here if the hydrostatic test was the governing design condition at this station.

2.2.7.6 UPD (I, 5)

UPD (I, 5) = $\sqrt{N_x^2 - N_x N_y + N_y^2}$ for maximum membrane load at station I.

2.2.7.7 UPD (I, 6)

UPD (I, 6) = time in flight at which maximum membrane load occurred.

2.2.7.8 UPD (I, 7)

UPD (I, 7) = N_x(b), the maximum buckling load (over time) at station I.

2.2.7.9 UPD (I, 8)

UPD (I, 8) = N_y(b), the loop load corresponding to the maximum buckling load.

2.2.7.10 UPD (I, 10)

UPD (I, 10) = time in flight at which maximum buckling load occurs.

2.2.7.11 UPD (I, 11)

UPD (I, 11) = N_x(d), corresponding to UPD (I, 13).

2.2.7.12 UPD (I, 12)

UPD (I, 12) = N_y(d), corresponding to UPD (I, 13).

2.2.7.13 UPD (I, 13)

UPD (I, 13) = maximum algebraic quantity over time of (N_x + N_y). Remember that signs are considered on all the stresses. This is a loading condition that must be considered for waffle construction stability, and is popularly called the "greatest difference load."

2.2.7.14 UPD (I, 14)

UPD (I, 14) = time in flight at which maximum "greatest difference load" occurs.

2.2.7.15 UPD (I, 15)

UPD (I, 15) = temperature at time of maximum membrane load.

2.2.7.16 UPD (I, 16)

UPD (I, 16) = temperature at time of maximum buckling load.

2.2.7.17 UPD (I, 17)

UPD (I, 17) = temperature at time of maximum "greatest difference load."

2.2.8 COMMON/LSECT/THICK (10, 15), NSHEET, LENSK, LEN, REQBAR, DIAM, SHEET

2.2.9 DIMENSION LIMIT (10, 15)

2.2.10 EQUIVALENCE (LIMIT, THICK)

This common contains sheet division information for the structural unit under consideration.

2.2.10.1 NSHEET

NSHEET = total number of sheets for this section.

2.2.10.2 LENSK

LENSK = height, if this is a conical section.

2.2.10.3 LEN

LEN = equivalent cylindrical length (may be different from LENSK if this conical section is not a cylinder).

2.2.10.4 REQBAR

REQBAR = equivalent cylinder radius for conical sections.

2.2.10.5 SHEET

SHEET = maximum sheet length for this construction (at one stage of computations), and later floating point form of NSHEET.

2.2.10.6 LIMIT (I, 1)

LIMIT (I, 1) = station at which sheet I starts (I may be from 1 to 10).

2.2.10.7 LIMIT (I, 2)

LIMIT (I, 2) = station at which sheet I ends.

2.2.10.8 LIMIT (I, 3)

LIMIT (I, 3) = station of maximum buckling load in sheet I.

2.2.10.9 LIMIT (I, 4)

LIMIT (I, 4) = station of maximum membrane load in sheet I.

2.2.10.10 LIMIT (I, 5)

LIMIT (I, 5) = station of maximum "greatest difference" load in sheet I.

2.2.10.11 THICK (I, 6) to THICK (I, 15)

THICK (I, 6) to THICK (I, 15) are spaces provided for each subprogram for bookkeeping of design parameters that vary sheet to sheet. This prevents space wasting by duplication for each subprogram.

2.2.11 COMMON/KONST/PI

COMMON/KONST/PI contains the constant 3.1415927.

2.2.12 COMMON/TEMRAN/ITEMPT, RANGE (10)

2.2.12.1 ITEMPT

ITEMPT = number of discrete temperatures for which material properties are stored in TPROP (I, J, K).

2.2.12.2 RANGE (1) to RANGE (ITEMPT)

RANGE (1) to RANGE (ITEMPT) = the actual temperature values (up to a maximum of ITEMPT equals 10).

2.2.13 COMMON/FABFAC/FABX (13)

This common contains fabrication for the various subprograms.

2.2.13.1 FABX (I)

FABX (I) = fabrication factor for conical section designed by construction subprogram I. (There are up to 10 subprograms.)

2.2.13.2 <u>Ellipsoidal Heads</u>

For ellipsoidal heads the fabrication factors are as follows:

a. FABX (11) for monocoque.

b. FABX (12) for honeycomb sandwich.

c. FABX (13) for waffle (45 degree and 90 degree are the same).

2.2.14 COMMON/SPACE/DATA (125)

Common used by the input routines for temporary storage while organizing input.

2.2.15 COMMON/SUE/NTAPE (12)

Common used to give logical unit numbers to the tapes needed by the program. Presently only NTAPE (1) through NTAPE (6) are used.

2.2.16 COMMON/OPTSET/NC (200)

2.2.17 DIMENSION CN (200)

2.2.18 EQUIVALENCE (NC, CN)

An array used to store signals for various modules of the executive program.

2.2.18.1 <u>NC (1)</u>

NC (1) = number of jobs.

2.2.18.2 <u>NC (2)</u>

NC (2) = type of job presently being done.

2.2.18.3 <u>NC (5)</u>

NC (5) = discontinuity at which to start computing optimum structures.

2.2.18.4 <u>NC (6)</u>

NC (6) = discontinuity at which to end computations.

2.2.18.5 <u>CN (7)</u>

CN (7) = yield stress safety factor for this job.

2.2.18.6 CN (8)

CN (8) = ultimate stress safety factor for this job.

2.2.18.7 NC (9)

NC (9) = signal for loads multiplier. NC (9) = 0 ⇒ no multiplier. NC (9) = 1 ⇒ yes.

2.2.18.8 CN (10)

CN (10) = actual value of multiplier to be used if NC (9) = 1.

2.2.18.9 NC (11)

NC (11) = run number to find on restart tape.

2.2.18.10 NC (12)

NC (12) = phase number to find on restart tape.

2.2.18.11 NC (140) and NC (141)

Signals used internally in waffle 45-degree and 90-degree programs.

2.2.18.12 NC (145)

NC (145) = number of subtotals for this job.

2.2.18.13 NC (150)

NC (150) = signal for whether subtotals matrix is desired. 1 ⇒ yes. 0 ⇒ no.

2.2.18.14 NC (151)

NC (151) = signal for printout of section by section matrix. 1 ⇒ yes. 0 ⇒ no.

2.2.18.15 NC (152)

NC (152) = signal for detailed output. 1 ⇒ yes. 0 ⇒ no.

2.2.18.16 NC (153)

NC (153) = signal for whether additional job type output matrices are wanted for jobs of types 2, 3, or 4.

2.2.18.17 NC (154)

NC (154) = job type of first additional output wanted.

2.2.18.18 NC (155)

NC (155) = job type of second additional output wanted.

2.2.19 COMMON/PLACEW/NPRW, NOPW, JOBNBR

2.2.19.1 NPRW

NPRW = the parameter setting number when performing a job of type 1.

2.2.19.2 NOPW

NOPW = the option setting number, when performing a job of type 5.

2.2.19.3 JOBNBR

JOBNBR = the job number in a series of stacked jobs.

2.2.20 COMMON/MONCOM/MONIN (3)

This common contains monocoque input.

2.2.21 COMMON/NEYCMB/HCIN (22)

This common contains honeycomb sandwich input.

2.2.22 COMMON/WAF45/W45IN (6)

This common contains waffle 45-degree input.

2.2.23 COMMON/WAF90/W90IN (6)

This common contains waffle 90-degree input.

2.2.24 COMMON/ARLENE/C1IN (6)

This common contains no-face corrugation input.

2.2.25 COMMON/SFCOR/C2IN (7)

This common contains single-face corrugation input.

2.2.26 COMMON/SMONIN/SMIN (16)

This common contains semi-monocoque input.

2.2.27 COMMON/INTINP/ISIN (5)

This common contains integral ring and stringer stiffened input.

2.2.28 COMMON/OUTPTS/BIGWT (50, 5, 6), WEIGHT, SWPRAM (50, 6)

2.2.29 EQUIVALENCE (BIGWT, SWPRAM)

2.2.29.1 <u>WEIGHT</u>

WEIGHT = weight of the structural section presently being optimized.

2.2.29.2 <u>BIGWT (I, J, K)</u>

BIGWT (I, J, K) = the weight of a single structural unit stored in an array for comparative weight matrix output, where:

a. I = the sequence for the structural section in this job. For example, I = 5 implies the fifth section.
b. J = the index of the subprogram used for this weight.
c. K = the index of the material used for this weight.

2.2.29.3 <u>SWPRAM (I, J)</u>

SWPRAM (I, J) = the weight of a single structural unit stored in an array for matrices of job type 1 or job type 5, where:

a. I = the sequence of this section in the series of sections considered for this job. For example, I = 5 means that this is the fifth section for this job.
b. J = the index indicating the option setting (job type 5) or the parameter setting (job type 1) used for this weight.

2.2.30 COMMON/SUBTOT/LIMSUB (10, 6)

This common block contains subtotaling information for outputting subtotal matrices.

2.2.30.1 LIMSUB (I, 1)

LIMSUB (I, 1) = discontinuity at which subtotal I starts.

2.2.30.2 LIMSUB (I, 2)

LIMSUB (I, 2) = discontinuity at which subtotal I ends.

2.2.30.3 LIMSUB (I, 3)

LIMSUB (I, 3) = signal on whether to include bottom head at starting discontinuity into the subtotal weight I. LIMSUB (I, 3) = 1 ⇒ include in subtotal. LIMSUB (I, 3) = 0 ⇒ do not include in subtotal.

2.2.30.4 LIMSUB (I, 4)

LIMSUB (I, 4) = signal on whether to include top head at starting discontinuity in subtotal I.

2.2.30.5 LIMSUB (I, 5)

LIMSUB (I, 5) = signal on whether to include bottom head at ending discontinuity in subtotal I.

2.2.30.6 LIMSUB (I, 6)

LIMSUB (I, 6) = signal on whether to include top head at ending discontinuity in subtotal I.

2.2.31 COMMON/NAMES/NAMMAT (12, 2), NAMSP (10, 2) NAMSTN (20, 3, 2) NAMSTG (10, 12)

2.2.31.1 NAMMAT (I, 1) to NAMMAT (I, 2)

NAMMAT (I, 1) to NAMMAT (I, 2) = two variables that contain a 12-character alphanumeric name for material I. This name is used for labeling output.

2.2.31.2 NAMSP (J, 1) to NAMSP (J, 2)

NAMSP (J, 1) to NAMSP (J, 2) = two variables that contain the 12-character name of subprogram J.

2.2.31.3 NAMSTN (K, L, 1) to NAMSTN (K, L, 2)

NAMSTN (K, L, 1) to NAMSTN (K, L, 2) = two variables that contain a 12-character name for the structural section of type L at discontinuity K.

2.2.31.4 NAMSTG (I, 1) to NAMST (I, 12)

NAMSTG (I, 1) to NAMST (I, 12) = a 72-character description of subtotal I. Used in labeling output.

2.2.32 COMMON/NAMPO/NAMOPN (6, 2), NAMPRM (6, 2)

2.2.32.1 NAMOPN (I, 1) to NAMOPN (I, 2)

NAMOPN (I, 1) to NAMOPN (I, 2) = a 12-character name used in labeling output for option setting I in jobs of type 5.

2.2.32.2 NAMPRM (I, 1) to NAMPRM (6, 2)

NAMPRM (I, 1) to NAMPRM (6, 2) = a 12-character name used in labeling output for STRESS parameter setting I in jobs of type 1.

2.3 TAPE ASSIGNMENTS

The program requires the following tape configurations.

2.3.1 JOBS INCLUDING STRESS SUBPROGRAM

These jobs require an input tape from the LASS1 program on FORTRAN Logical Unit NTAPE1, a scratch tape on NTAPE2, a scratch tape on NTAPE3, and a restart save tape on NTAPE4.

2.3.2 JOBS RUN FROM THE STRESS RESTART TAPE

These jobs require only that the restart tape be mounted on FORTRAN Logical Unit NTAPE4.

The system input tape is designated as NTAPE5, and the system output tape is designated at NTAPE6.

The designations NTAPE1 through NTAPE6 are variable units the actual values of which for each location are compiled into the block data routine of stored data.

Standard IBM installations for both the IBM 7094 and IBM 7044 accept the following values for the variable FORTRAN Logical Unit assignments:

a. NTAPE1 = 1
b. NTAPE2 = 2
c. NTAPE3 = 3
d. NTAPE4 = 4
e. NTAPE5 = 5
f. NTAPE6 = 6.

Thus a statement of the form WRITE (NTAPE6, 100) A, B, C is equivalent to the statement WRITE (6, 100) A, B, C when NTAPE6 has been set equal to 6 by the block data routine.

The physical unit to FORTRAN Logical Unit assignments are handled by control cards particular to each installation.

2.4 TIMING CONSIDERATIONS

Timing varies from computer to computer. However, approximate running time estimates may be obtained for a given computer by multiplying running times on one computer by an appropriate conversion factor.

The SWOP program was developed and checked out on the IBM 7094. Checkout experience indicates the following estimated running times for IBM 7094's:

a. Compilation: approximately 20 minutes.
b. Loading: 1.5 minutes.
c. STRESS Program: 2 minutes per case for a Saturn V type vehicle of 14 discontinuities and 4-inch station intervals.
d. Construction subprograms: an average time of 0.4 minutes per construction for one complete 14 discontinuity Saturn V type vehicle. For example, a comparative weight matrix of five constructions would take an average of 2.0 minutes to compute. The times for each construction vary because of the varying complexities of the several optimization procedures.

An interval timer feature to time each stacked job in seconds is available for the IBM 7094 computer, and provision is made for any other type facility to also add this capability.

2.5 ERROR RETURNS

The executive control program prints out several diagnostic messages on errors it detects in the input. These are in addition to the error diagnostic procedures performed by each construction subprogram, which are described in the sections appropriate to them.

2.5.1 MAIN CONTROL PROGRAM

The main control program XQTIVE checks that control cards are in proper sequence. An out-of-sequence card, or a card that is unrecognizable or incorrect will cause the program to print an error message and stop. The ID word (columns 1 to 6) of the incorrect card is printed out.

2.5.2 INPUT PROCESSING ROUTINE

The input processing routine CASEIN checks for unrecognizable cards and calls exit if one is encountered.

2.5.3 INTERPOLATE ROUTINE

The routine INTERP which interpolates on temperature dependent material properties prints a diagnostic message if the input temperature from the restart tape is outside the range of the table of material properties. It does not stop the program, however, but returns the material properties for the closest boundary value.

2.5.4 MATRIX OUTPUT ROUTINE

The matrix output routine MATRIX checks for input signals that ask for conflicting types of output, such as asking for more than one matrix from a job of type 5. It prints a diagnostic message and bypasses printout of the impossible output.

2.5.5 LOOP ROUTINE

The routine LOOP is constructed in such a way that incorrectly input subprogram material loops are omitted from the table. This routine also prints out diagnostic messages if the run, phase, or structural sections it has been instructed to perform computations for are not on the restart tape. If some of the sections are on the restart tape, it will call for computations on these sections and then go on to the next job. If none of the required sections or runs are on the restart tape, exit is called for and executed.

FLOW CHARTS

FORTRAN STRUCTURAL WEIGHT OPTIMIZATION PROGRAM

D I M E N S I O N E D   V A R I A B L E S

SYMBOL	STORAGES	SYMBOL	STORAGES	SYMBOL	STORAGES	SYMBOL	STORAGES	SYMBOL	STORAGES
SWPRAM	50,6	IDATA	125	NC	200	WORDS	10		

Figure 2-2. SWOP Flow Chart - XQTIVE (Sheet 1 of 5)

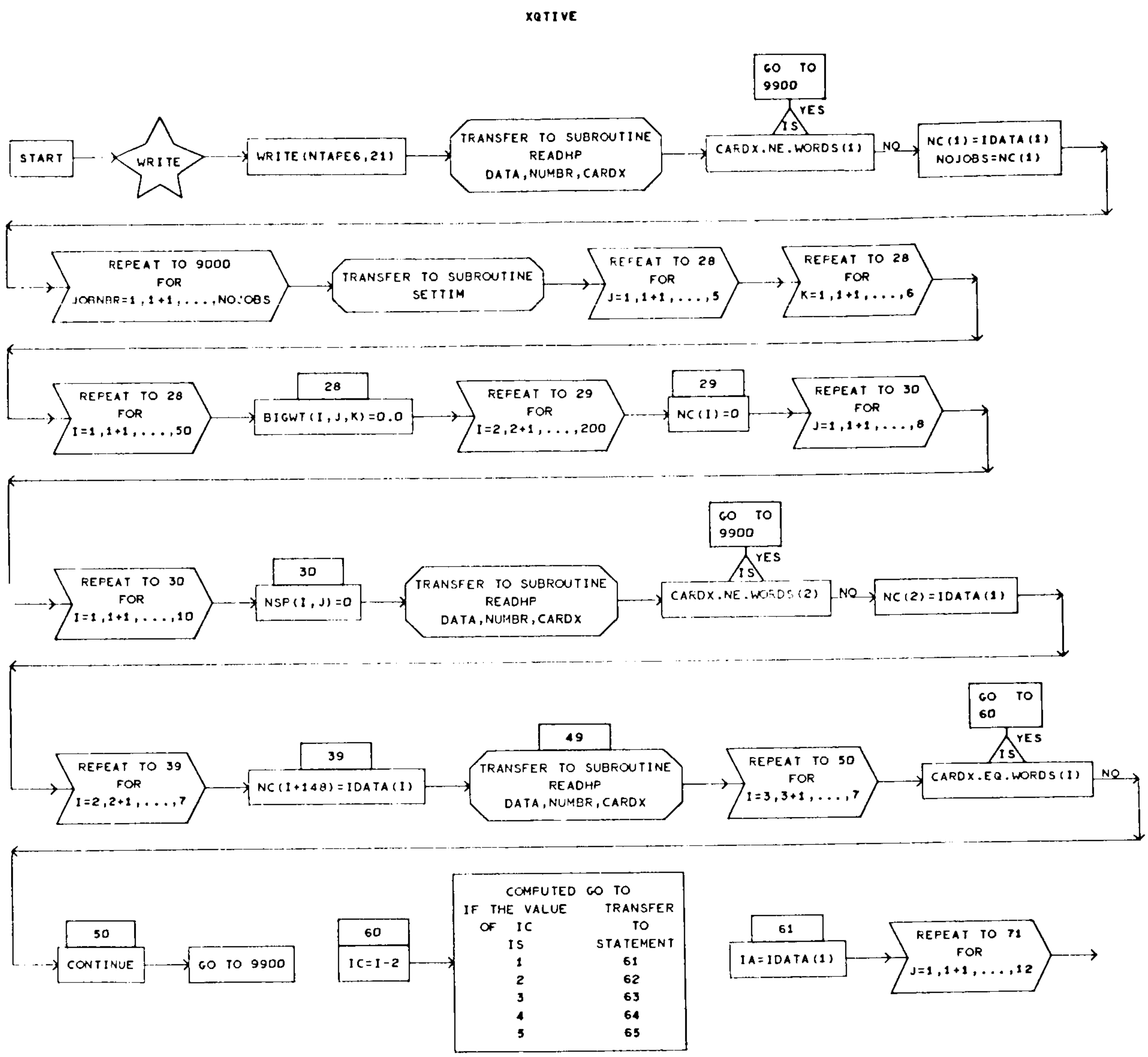


Figure 2-2. SWOP Flow Chart - XQTIVE (Sheet 2 of 5)

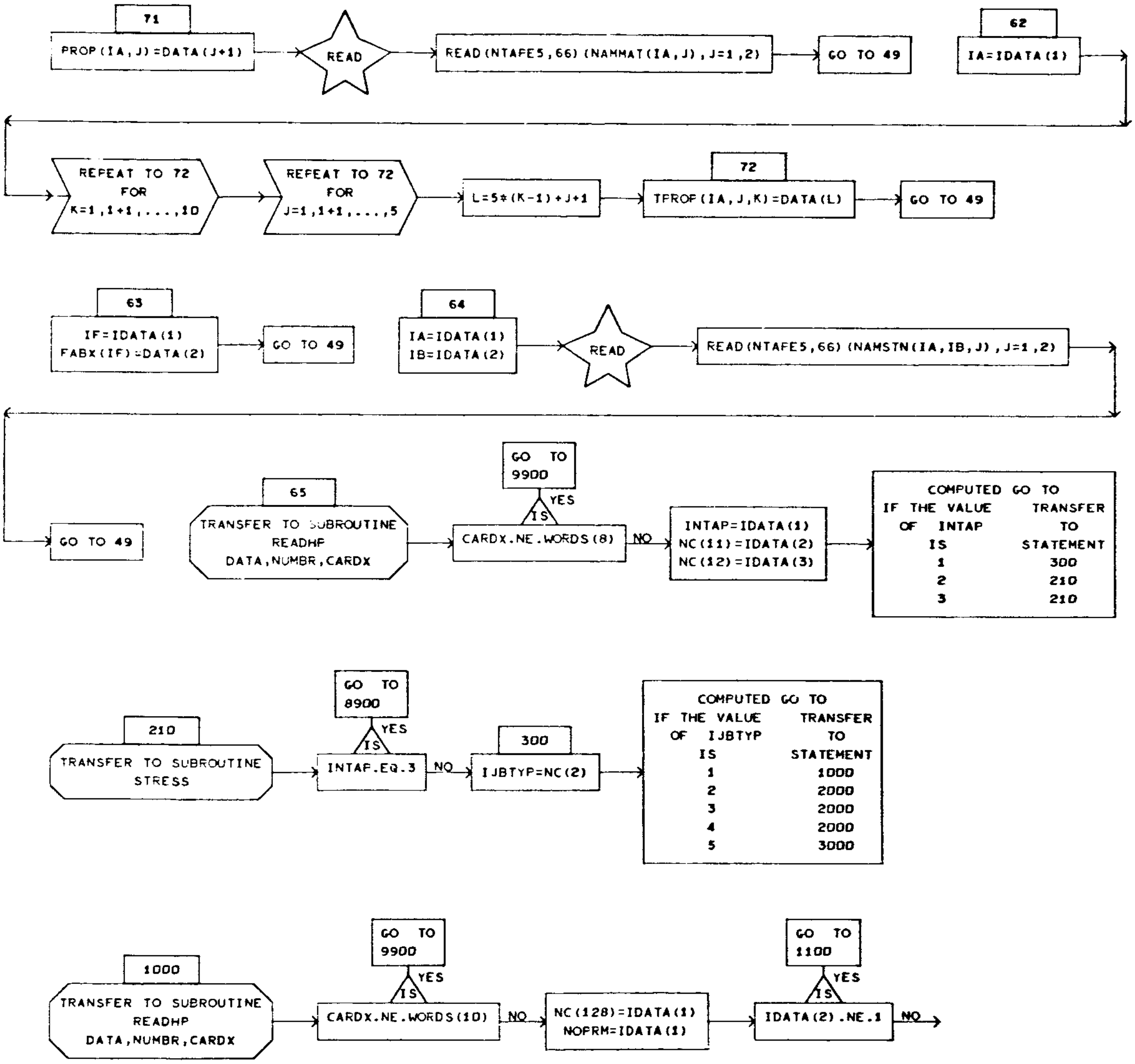


Figure 2-2. SWOP Flow Chart - XQTIVE (Sheet 3 of 5)

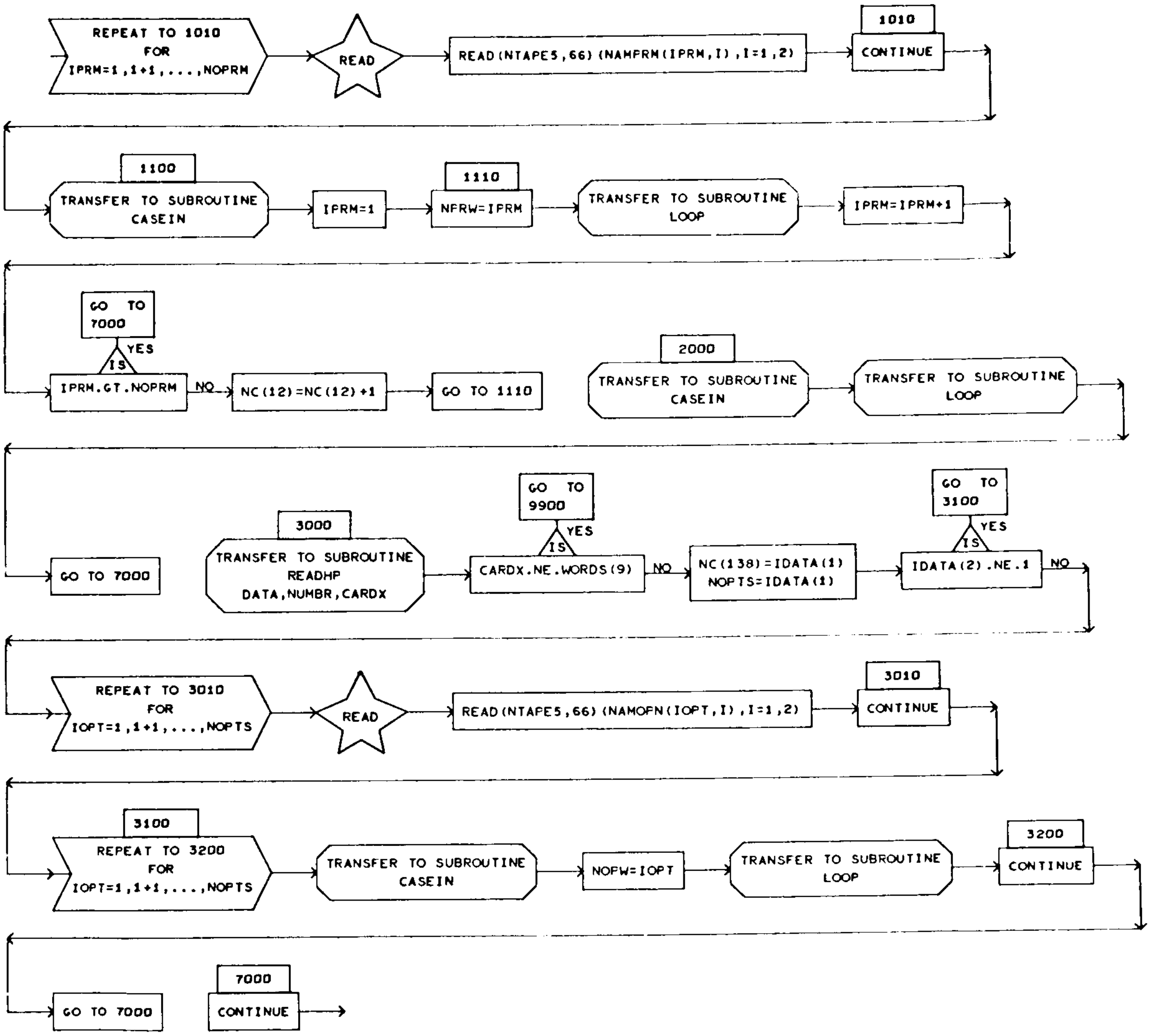


Figure 2-2. SWOP Flow Chart - XQTIVE (Sheet 4 of 5)

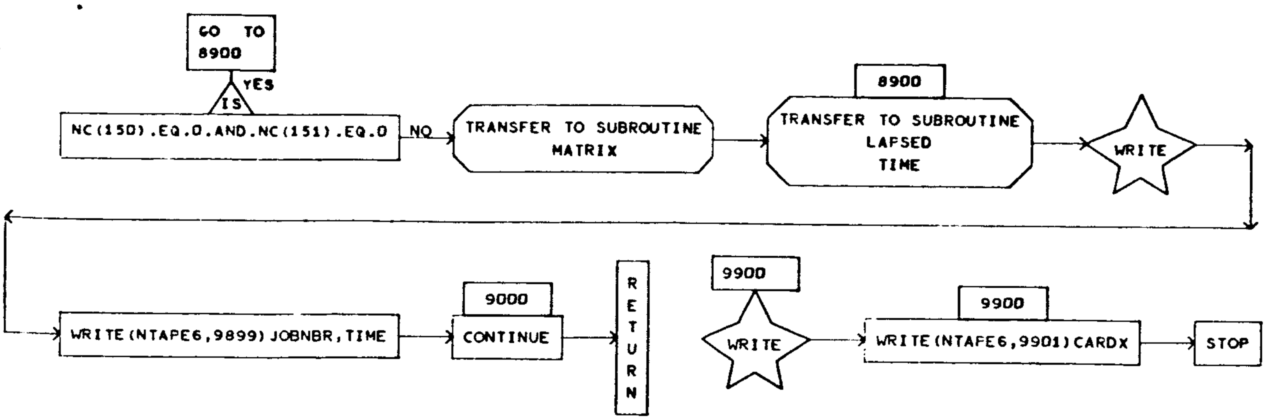


Figure 2-2. SWOP Flow Chart - XQTIVE (Sheet 5 of 5)

D I M E N S I O N E D   V A R I A B L E S

SYMBOL	STORAGES	SYMBOL	STORAGES	SYMBOL	STORAGES	SYMBOL	STORAGES	SYMBOL	STORAGES
CN	200	YCARD	30	IDATA	125				

Figure 2-3. SWOP Flow Chart - INCASE (Sheet 1 of 4)

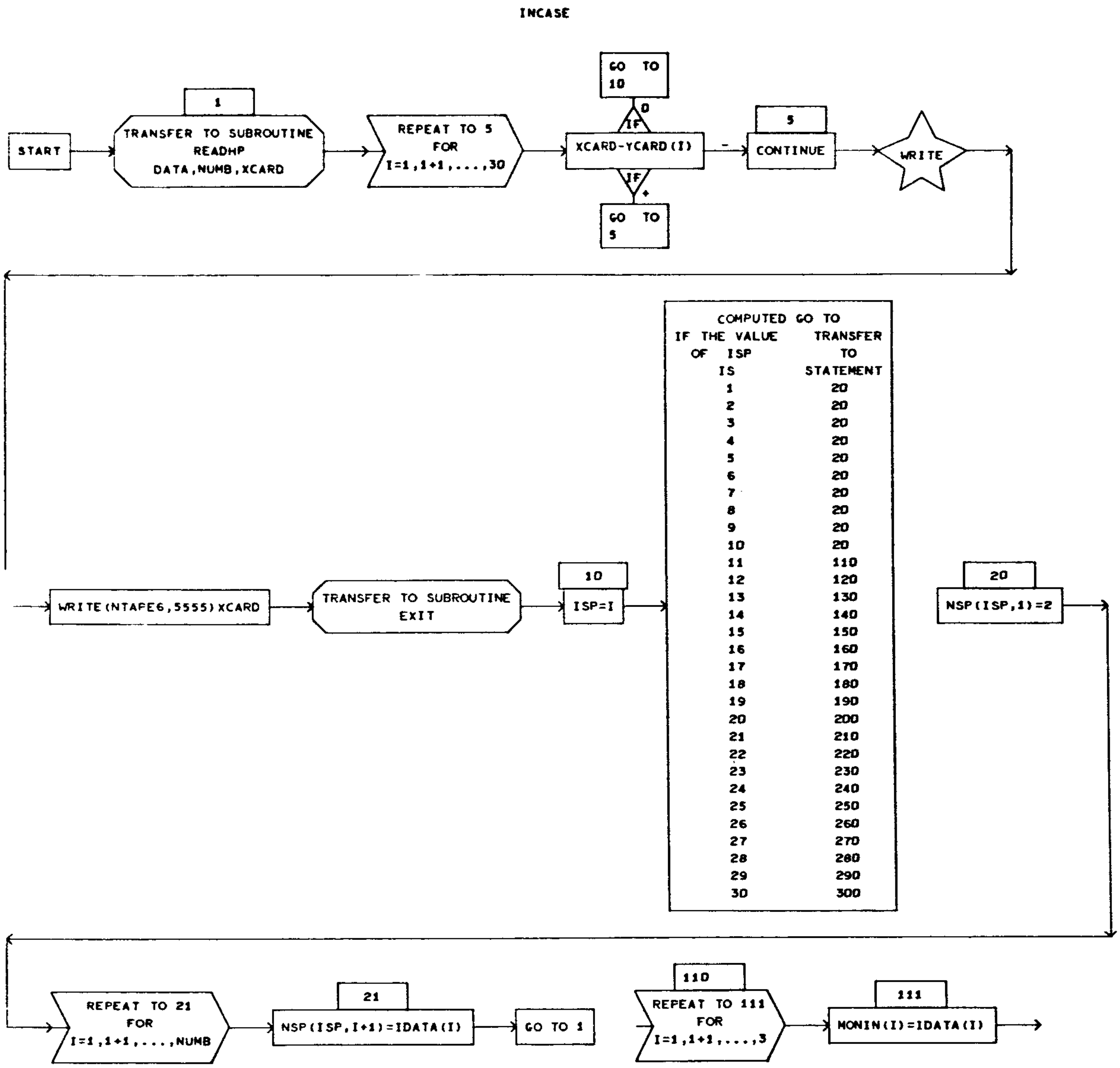


Figure 2-3. SWOP Flow Chart - INCASE (Sheet 2 of 4)

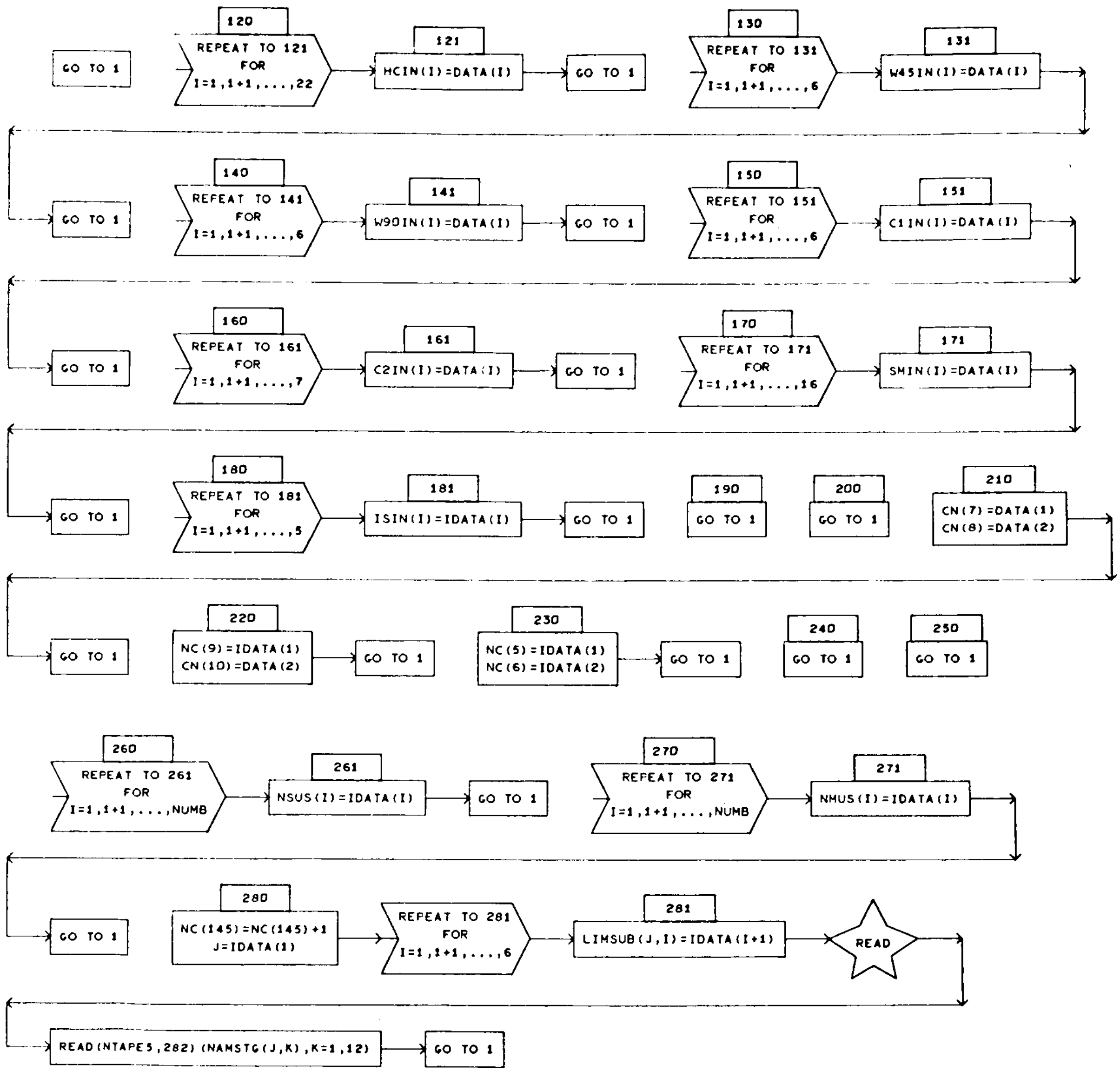


Figure 2-3. SWOP Flow Chart - INCASE (Sheet 3 of 4)

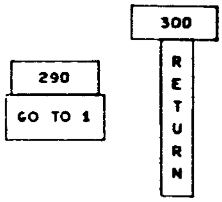


Figure 2-3. SWOP Flow Chart - INCASE (Sheet 4 of 4)

D I M E N S I O N E D   V A R I A B L E S

SYMBOL	STORAGES	SYMBOL	STORAGES	SYMBOL	STORAGES	SYMBOL	STORAGES	SYMBOL	STORAGES
SWPRAM	50,6	SUBPRM	10,6	TOTS	6	NAMTEM	5,2	TEMNAM	6,2

Figure 2-4. SWOP Flow Chart - MTRX (Sheet 1 of 11)

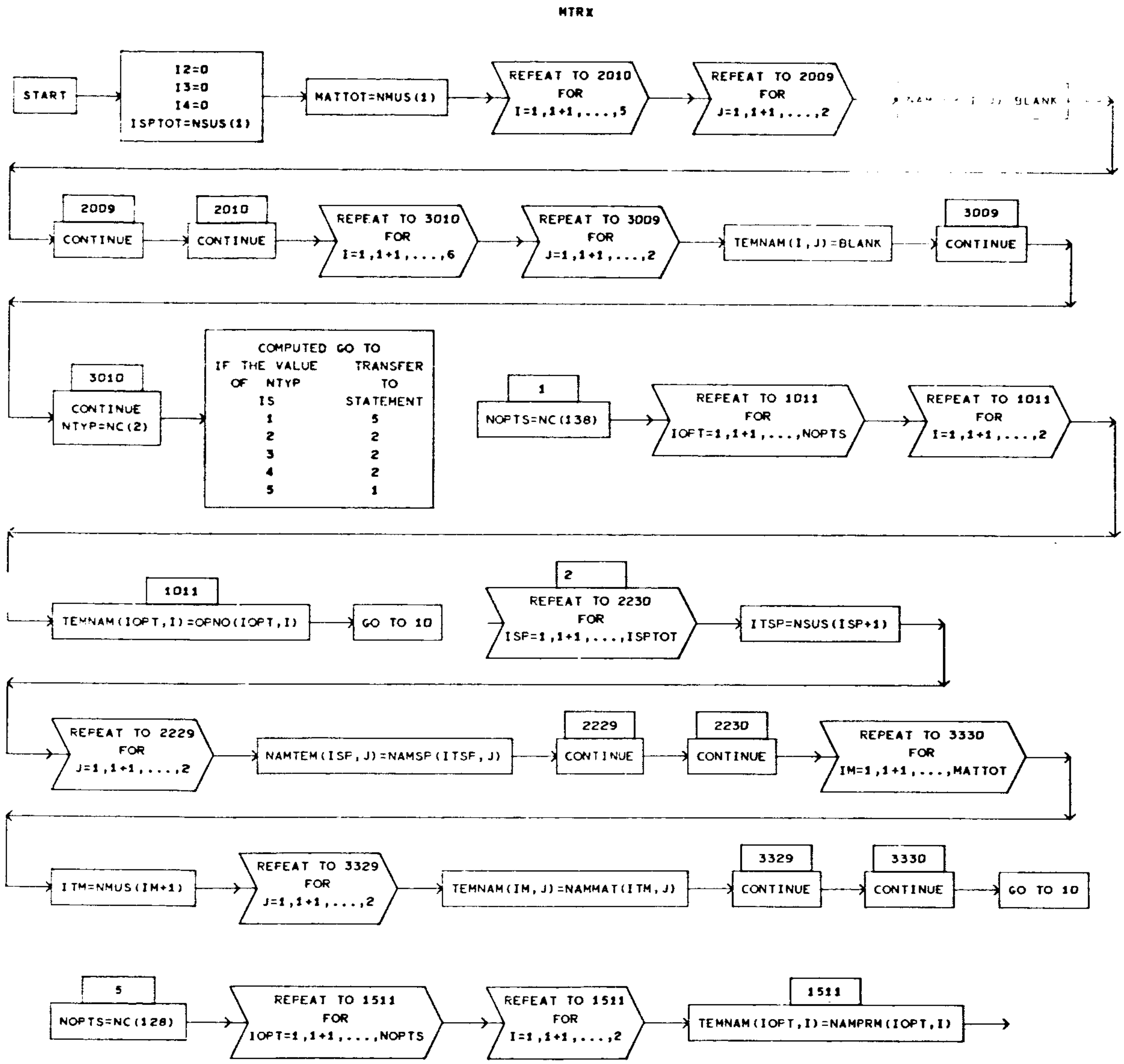


Figure 2-4. SWOP Flow Chart - MTRX (Sheet 2 of 11)

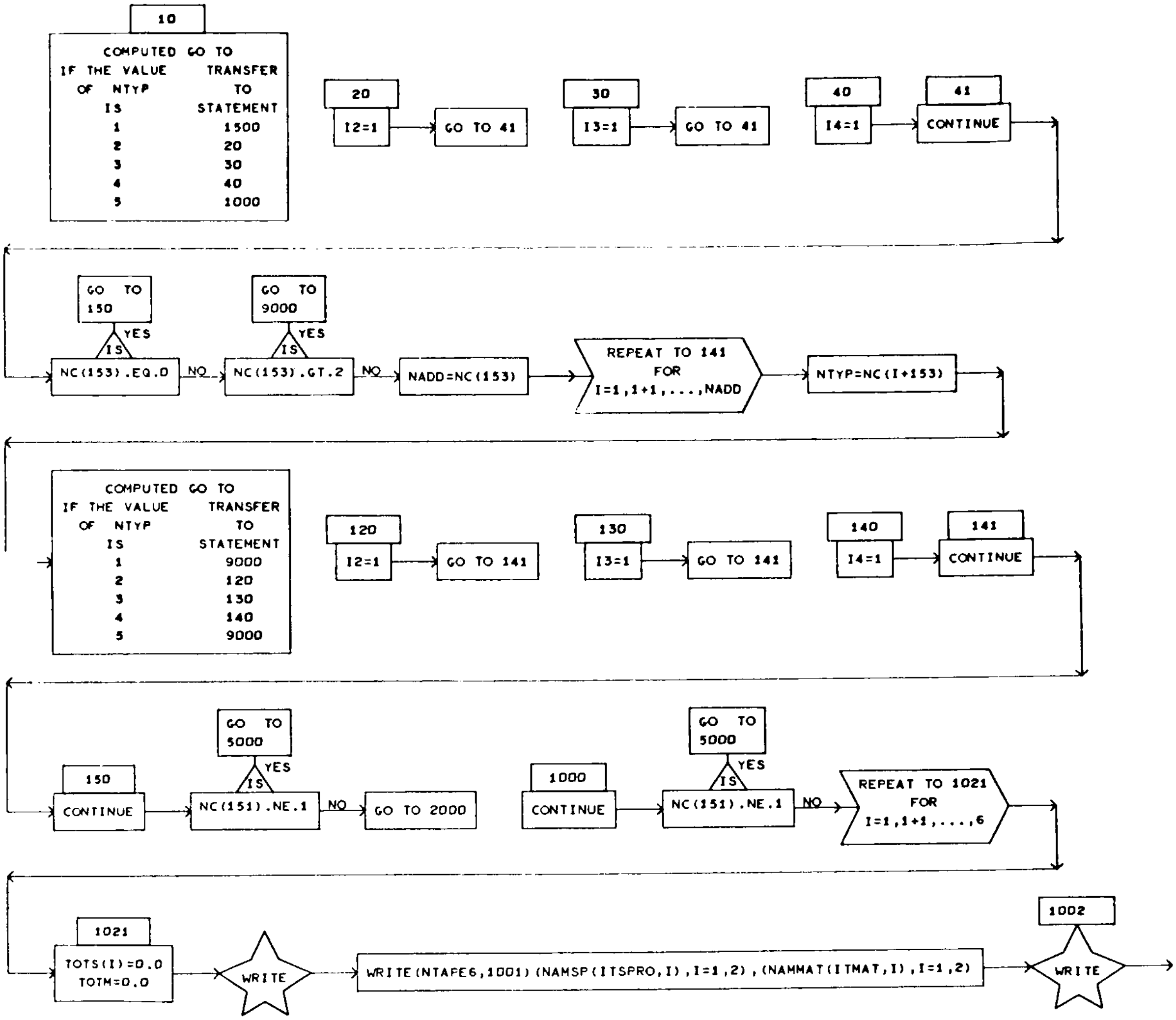


Figure 2-4. SWOP Flow Chart - MTRX (Sheet 3 of 11)

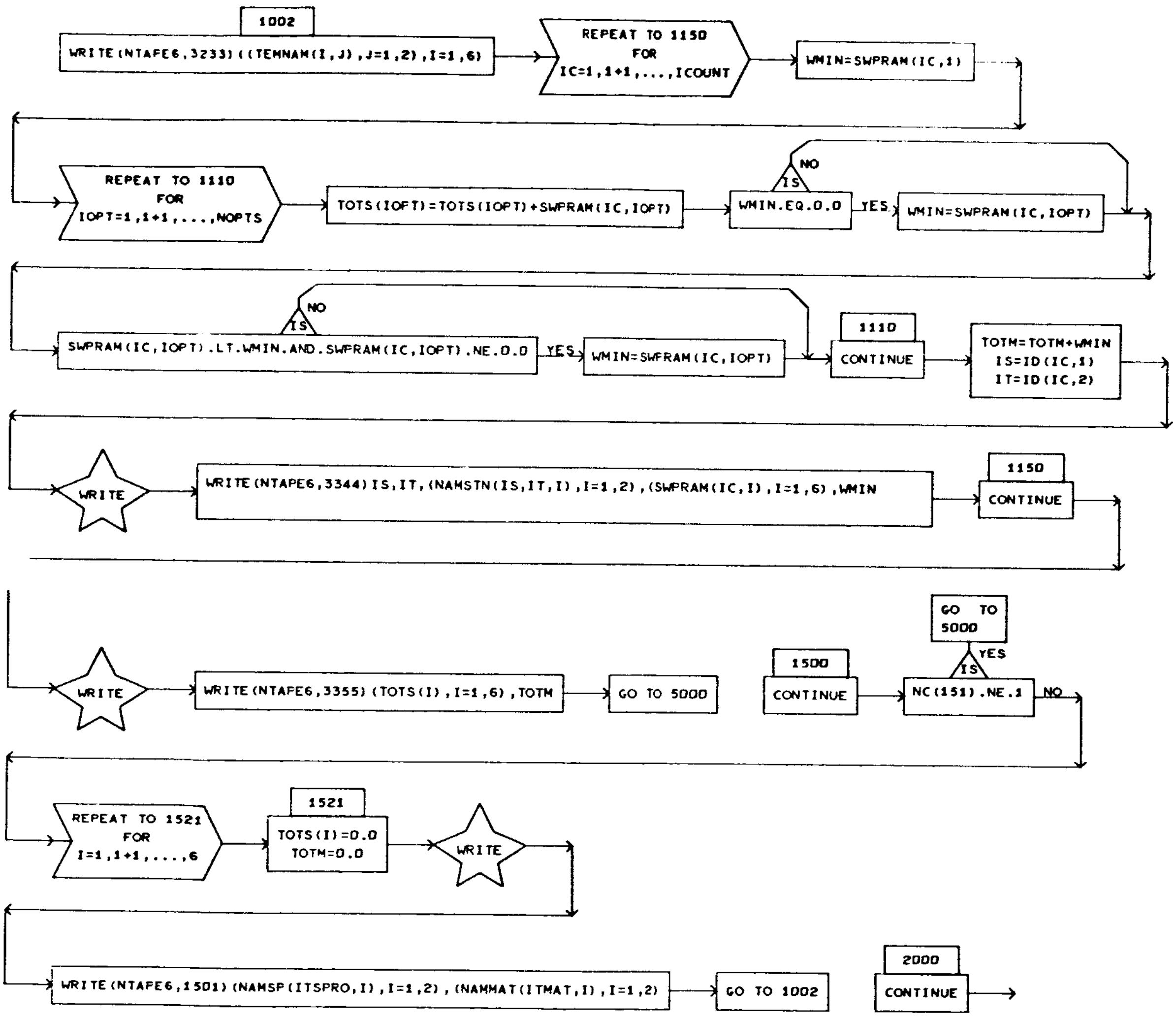


Figure 2-4. SWOP Flow Chart - MTRX (Sheet 4 of 11)

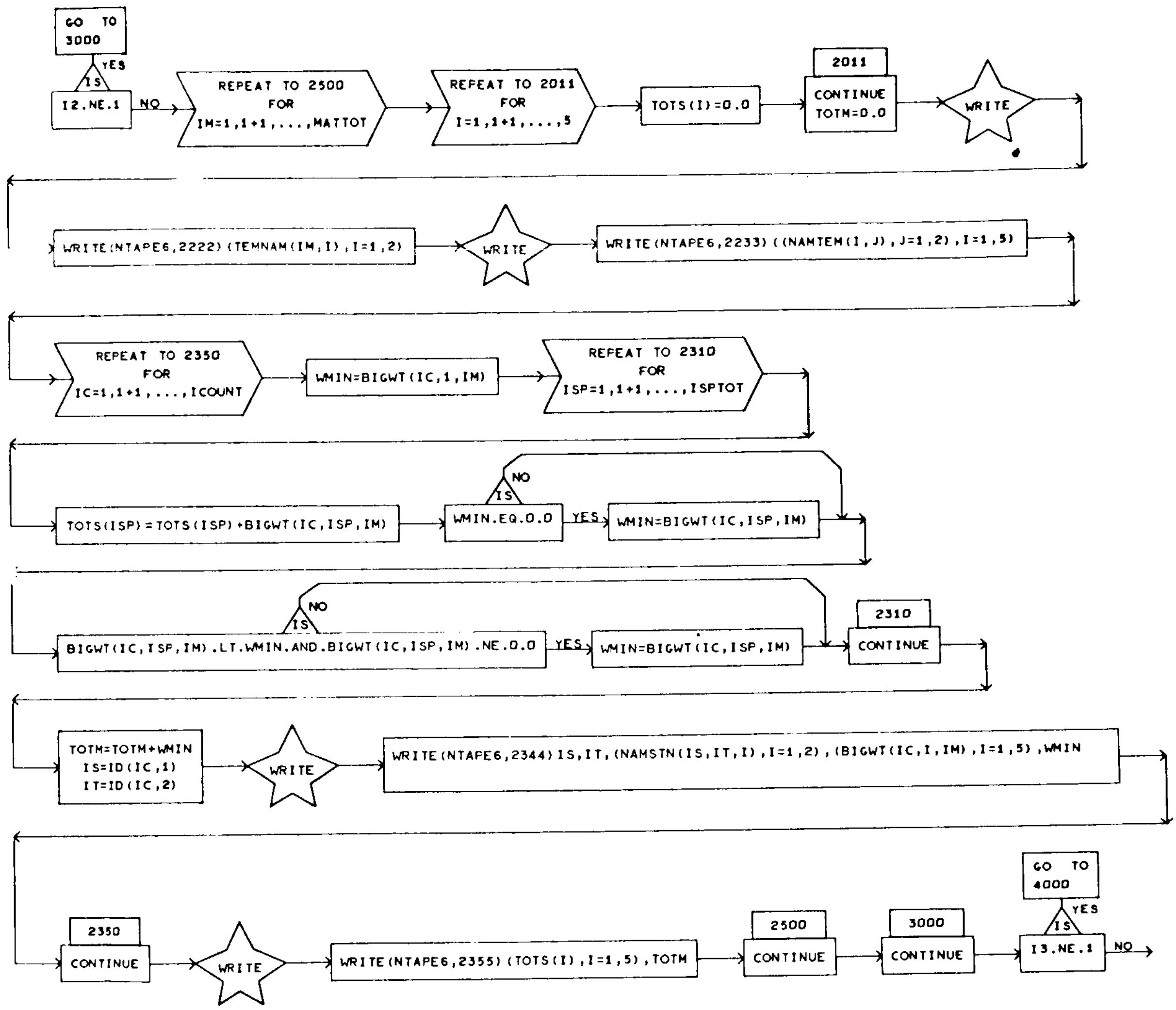


Figure 2-4. SWOP Flow Chart - MTRX (Sheet 5 of 11)

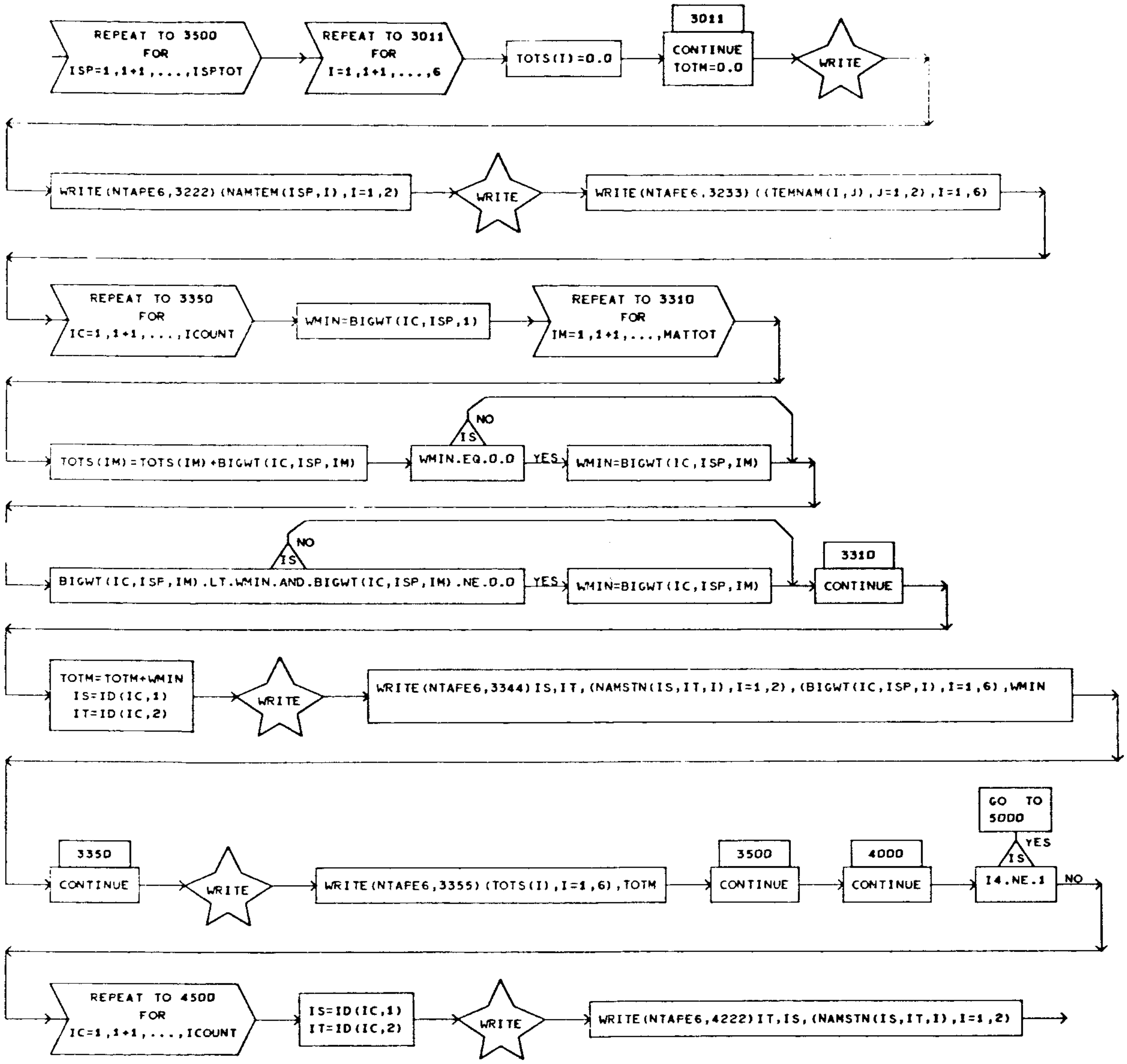


Figure 2-4. SWOP Flow Chart - MTRX (Sheet 6 of 11)

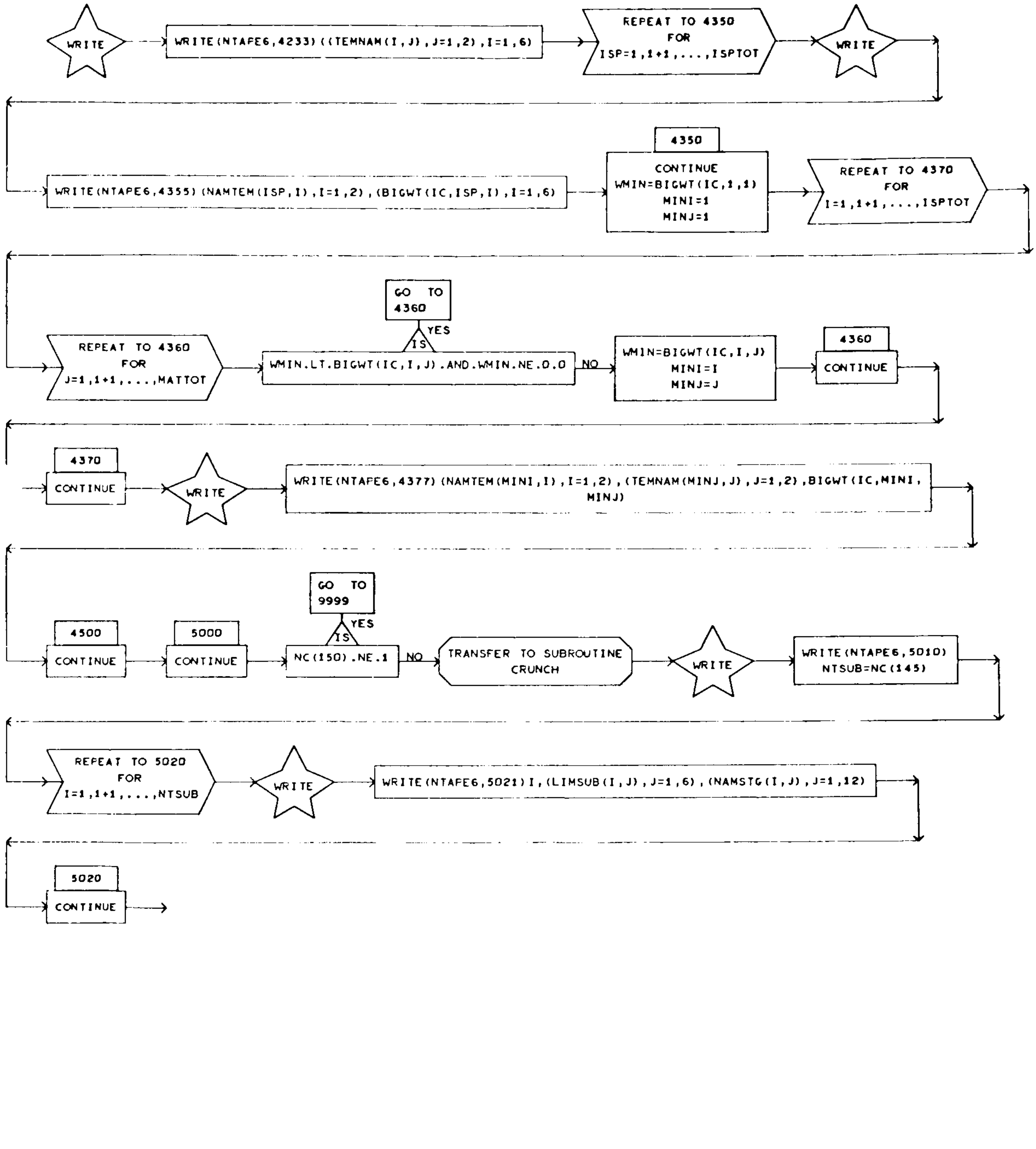


Figure 2-4. SWOP Flow Chart - MTRX (Sheet 7 of 11)

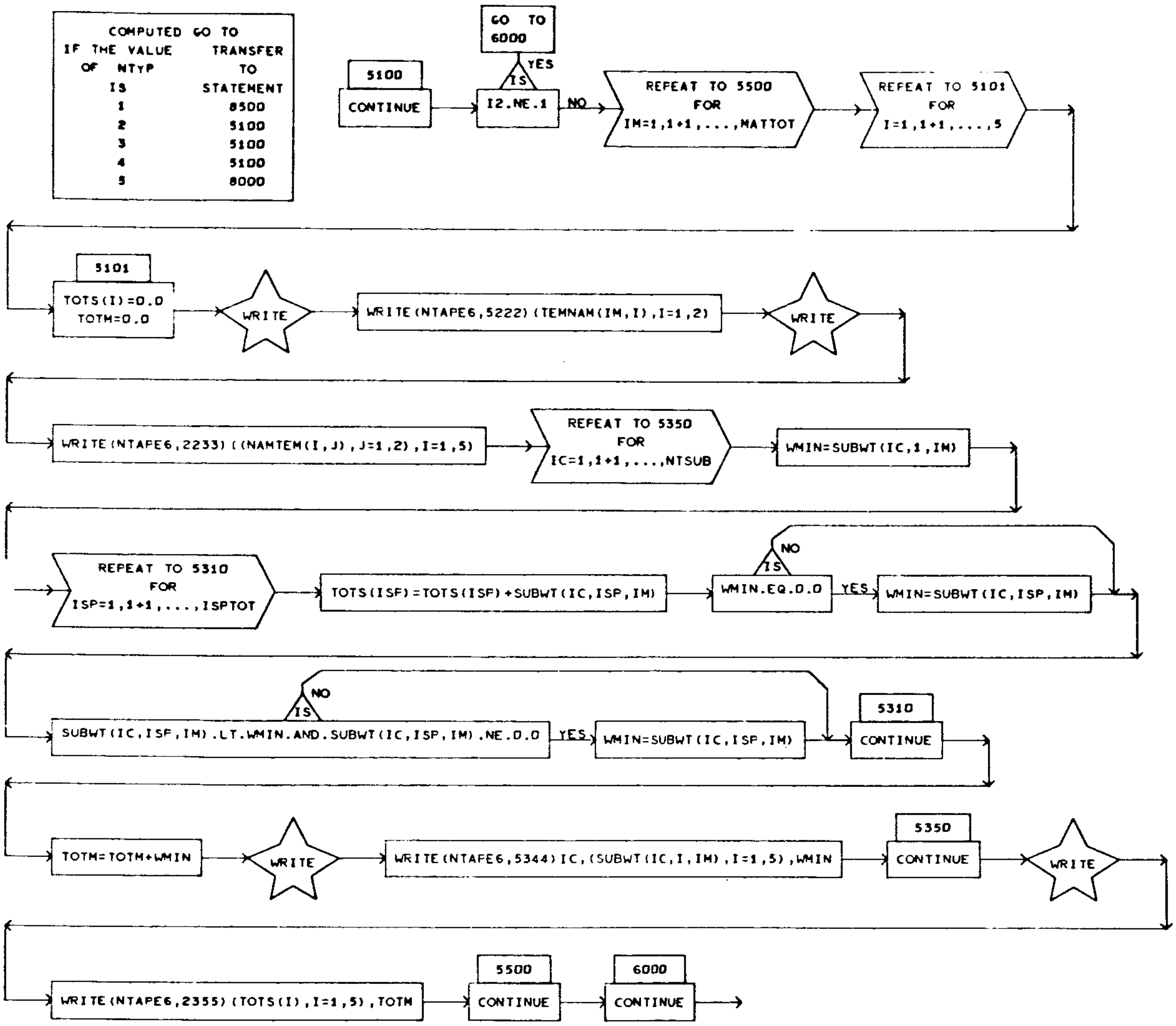


Figure 2-4. SWOP Flow Chart - MTRX (Sheet 8 of 11)

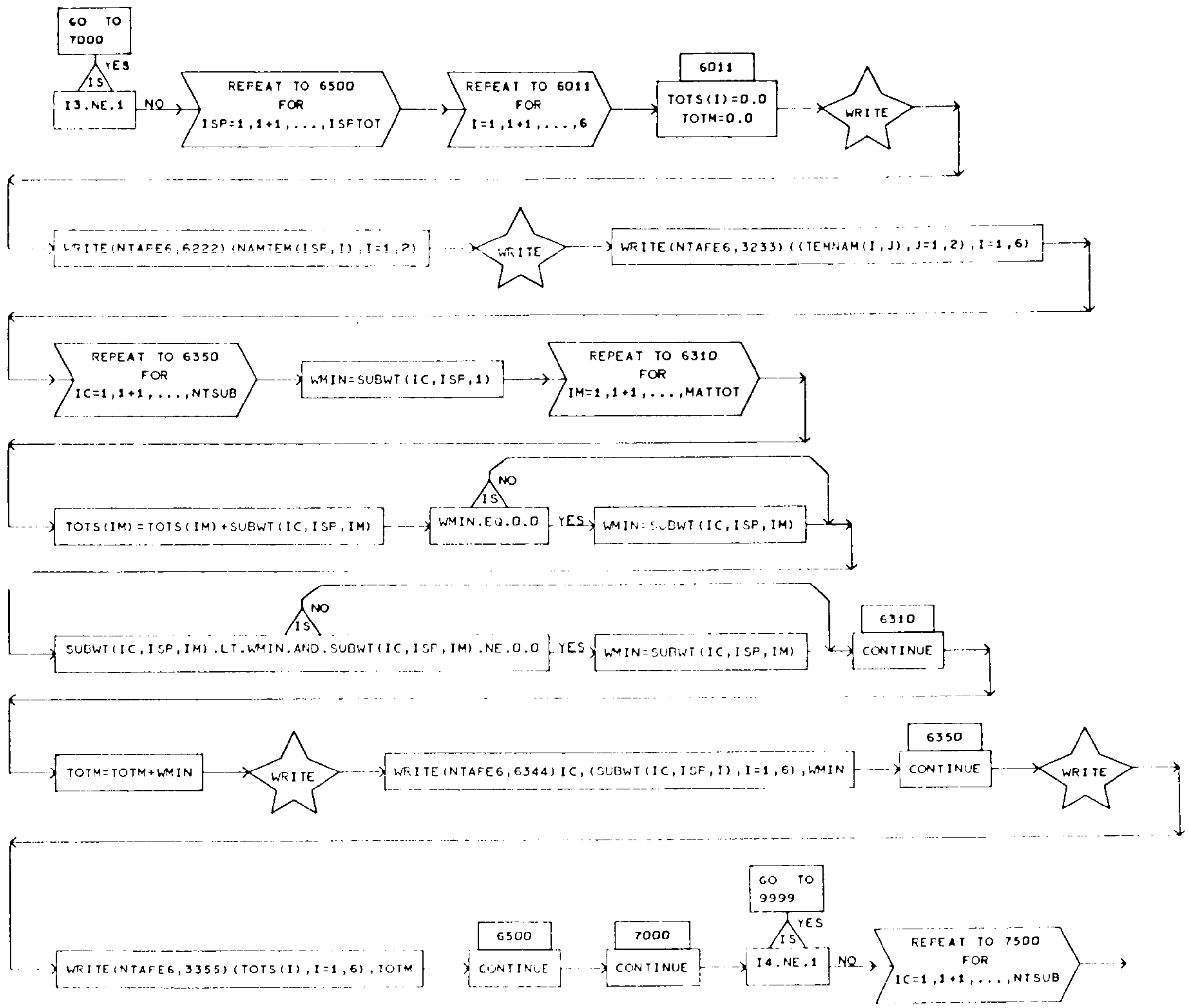


Figure 2-4. SWOP Flow Chart - MTRX (Sheet 9 of 11)

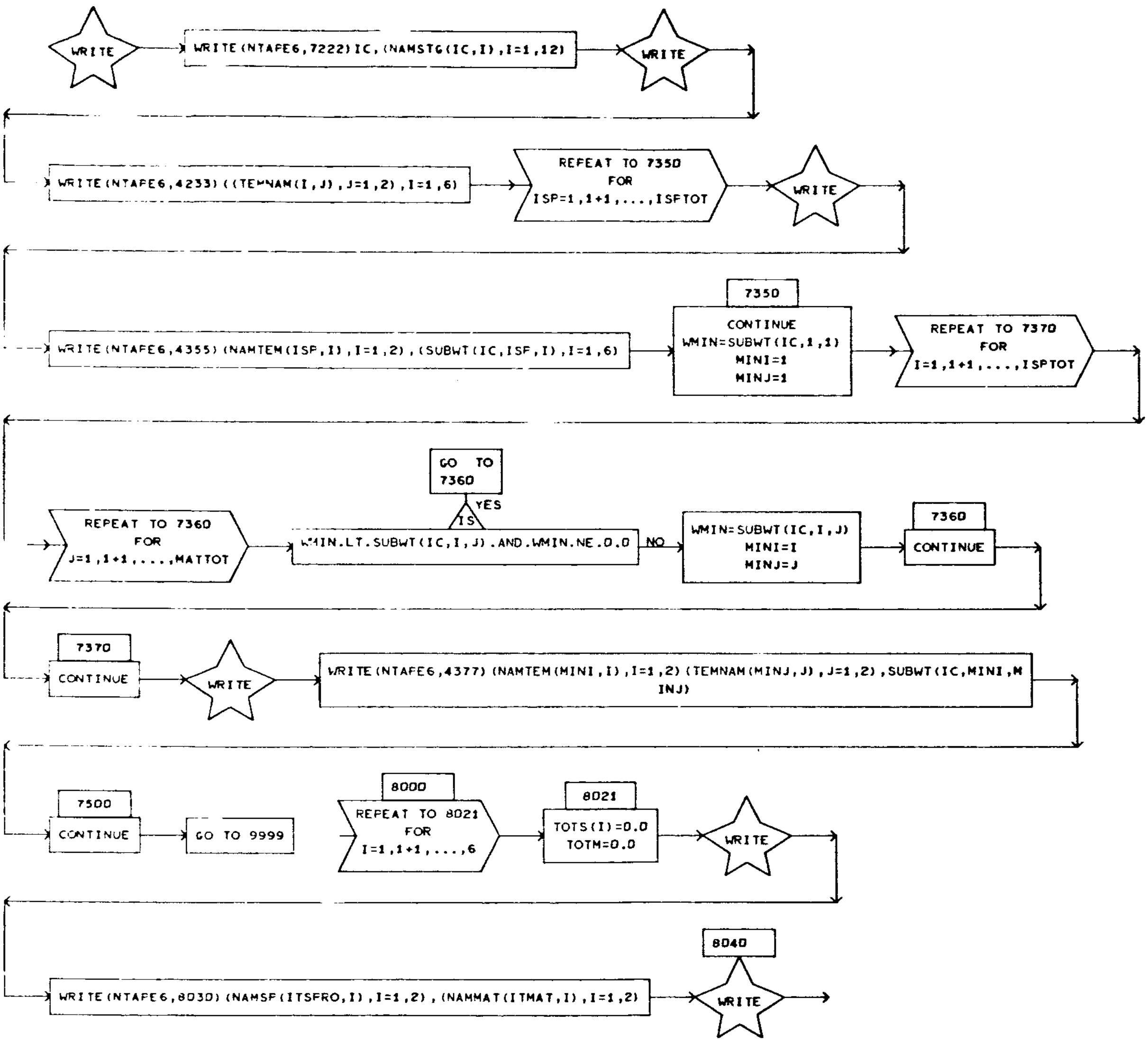


Figure 2-4. SWOP Flow Chart - MTRX (Sheet 10 of 11)

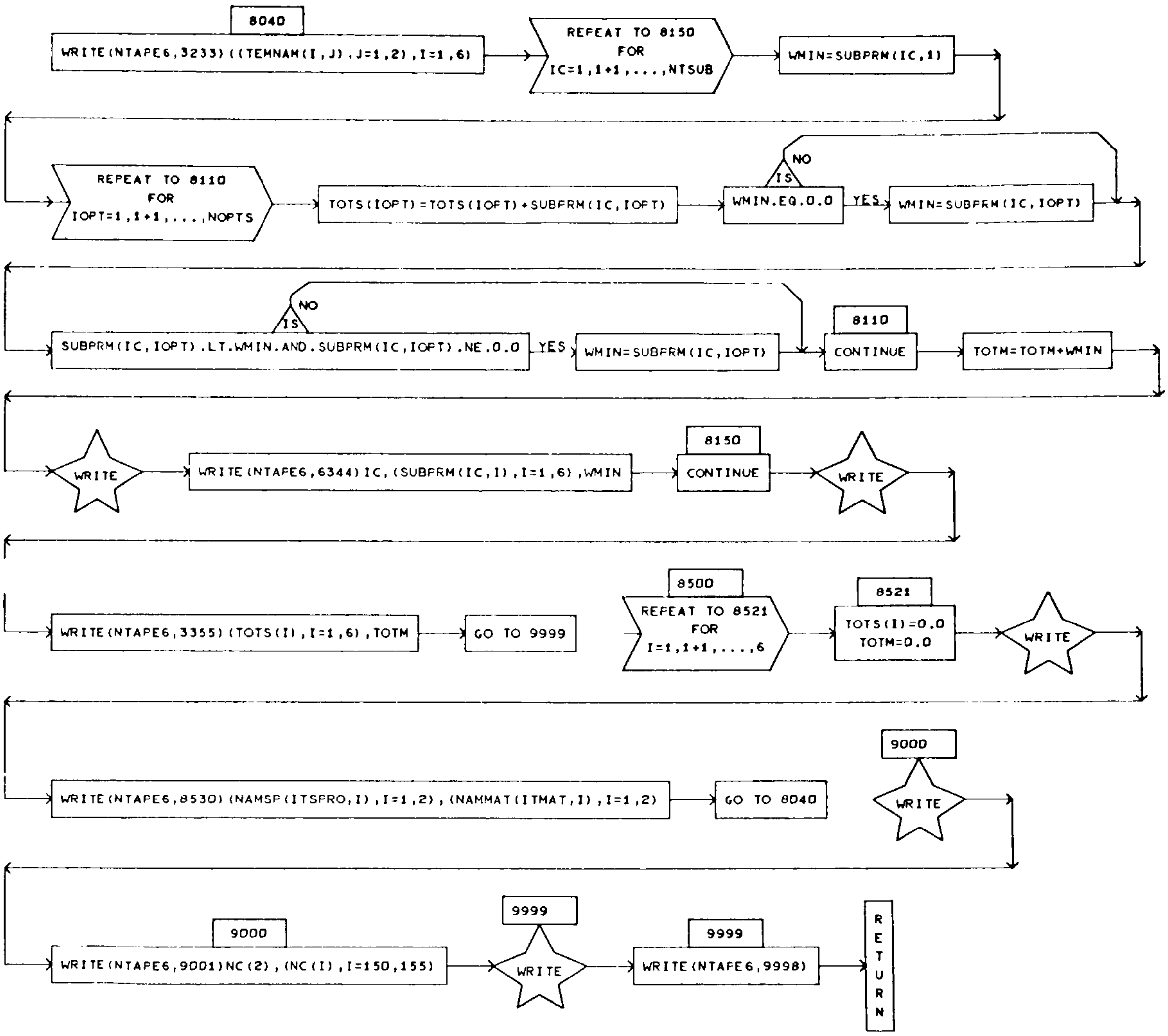


Figure 2-4. SWOP Flow Chart - MTRX (Sheet 11 of 11)

D I M E N S I O N E D   V A R I A B L E S

SYMBOL	STORAGES	SYMBOL	STORAGES	SYMBOL	STORAGES	SYMBOL	STORAGES	SYMBOL	STORAGES
SWPRAM	50,6	SUBPRM	10,6						

Figure 2-5. SWOP Flow Chart - CRNCH (Sheet 1 of 3)

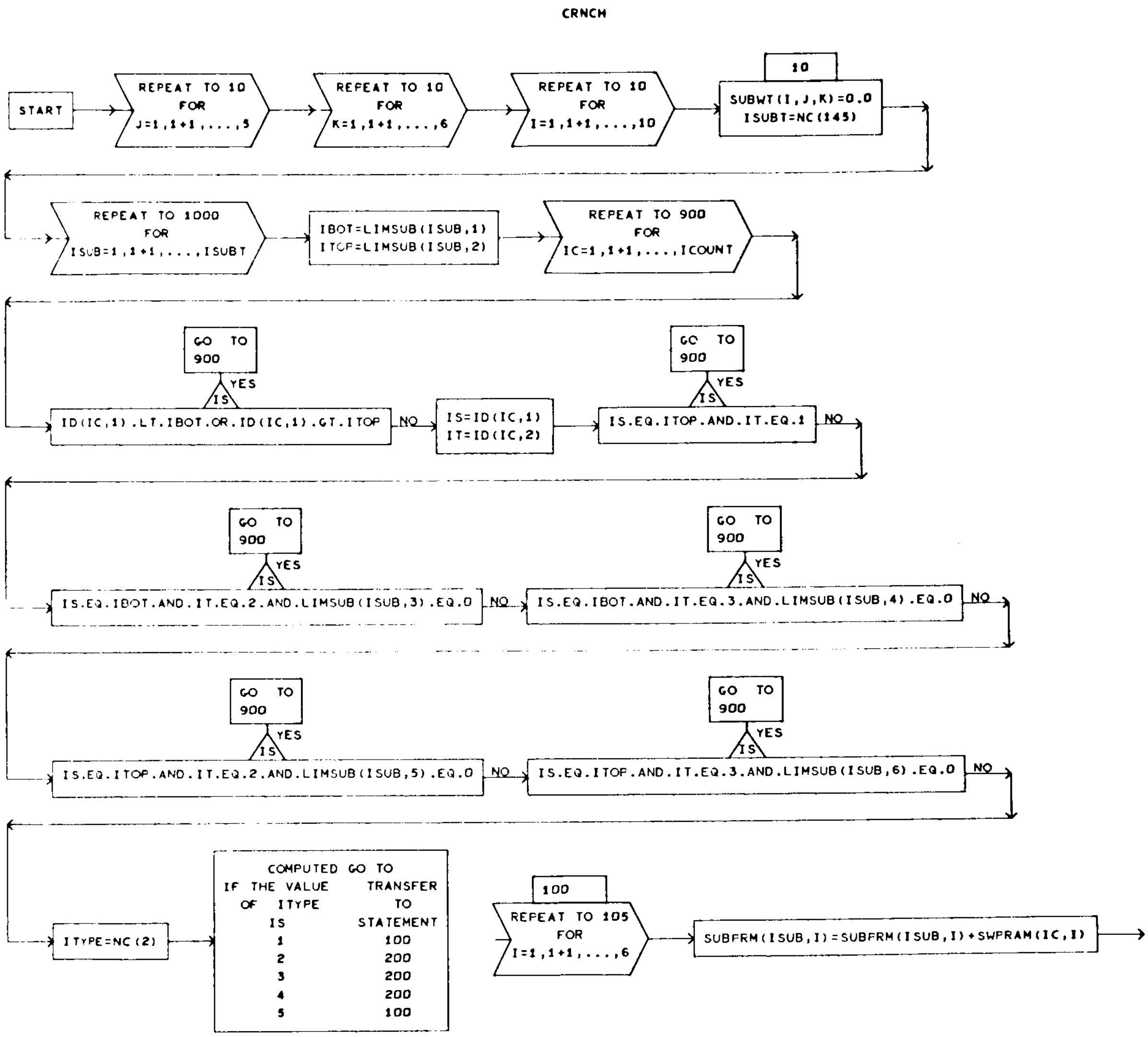


Figure 2-5. SWOP Flow Chart - CRNCH (Sheet 2 of 3)

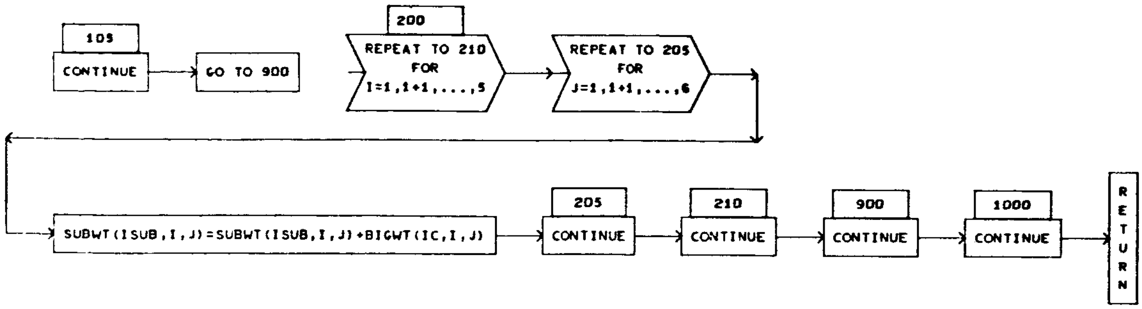


Figure 2-5. SWOP Flow Chart - CRNCH (Sheet 3 of 3)

DIMENSIONED VARIABLES

SYMBOL	STORAGES	SYMBOL	STORAGES	SYMBOL	STORAGES	SYMBOL	STORAGES	SYMBOL	STORAGES
SWPRAM	50,6	CN	200	LIMIT	10,15				

Figure 2-6. SWOP Flow Chart - LOOPP (Sheet 1 of 7)

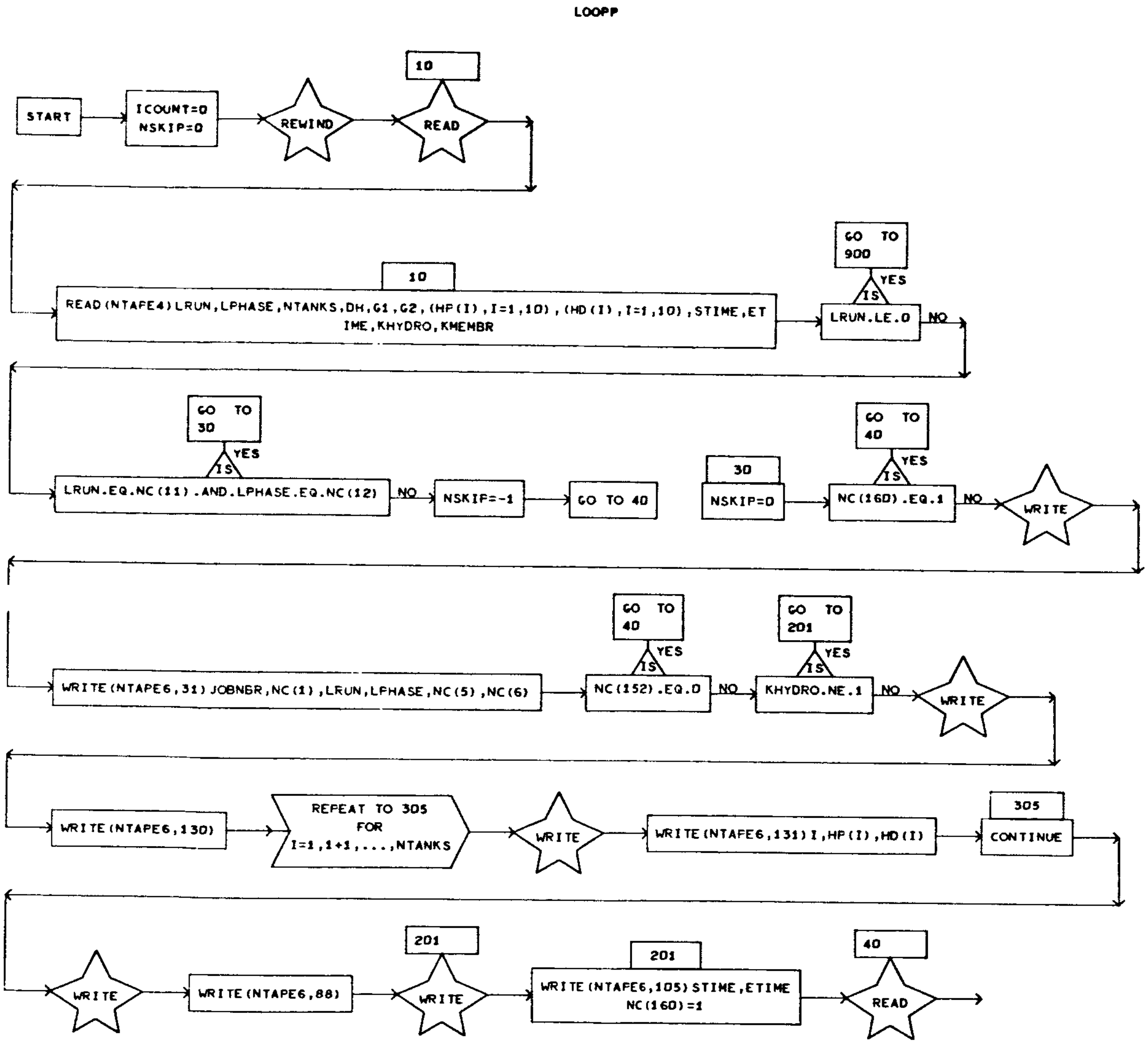


Figure 2-6. SWOP Flow Chart - LOOPP (Sheet 2 of 7)

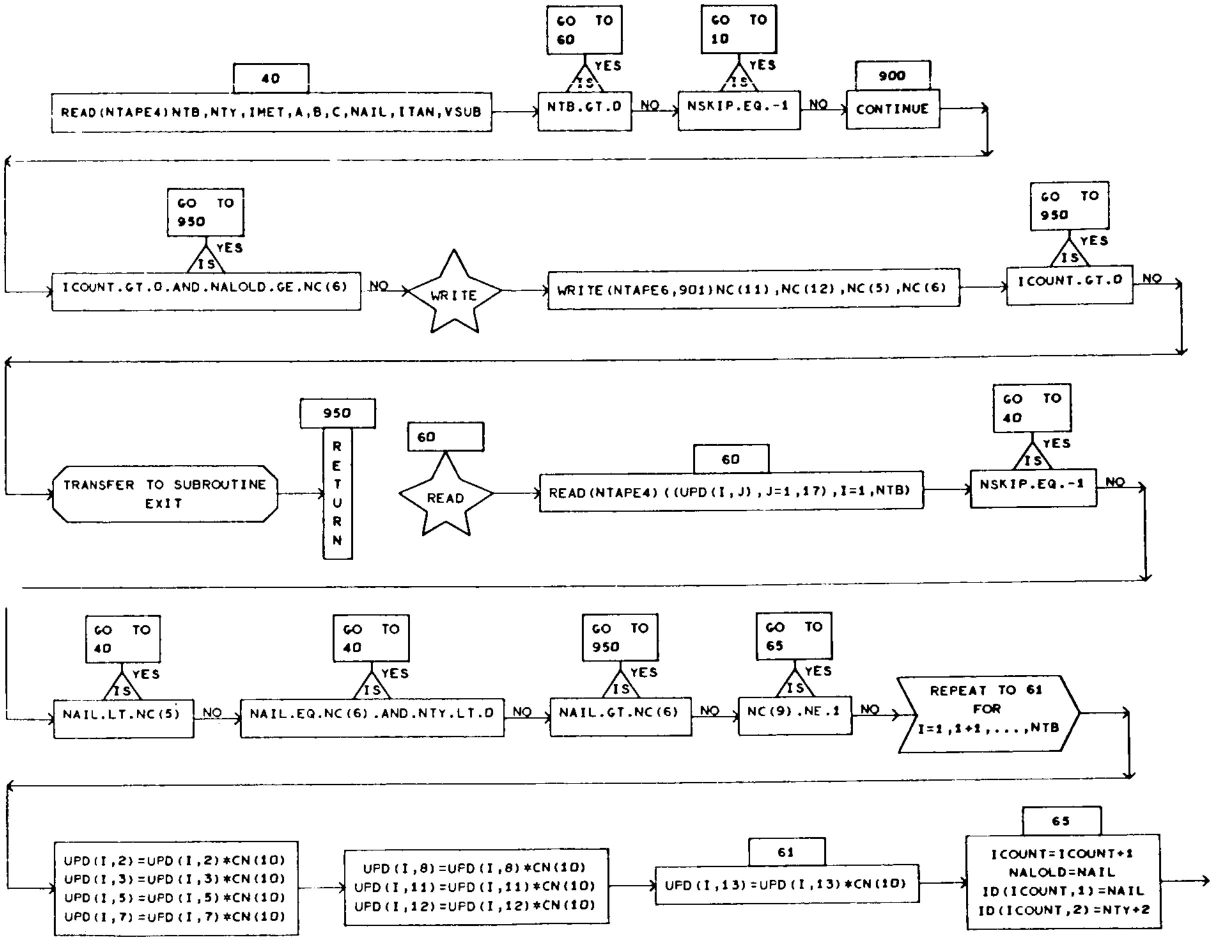


Figure 2-6. SWOP Flow Chart - LOOPP (Sheet 3 of 7)

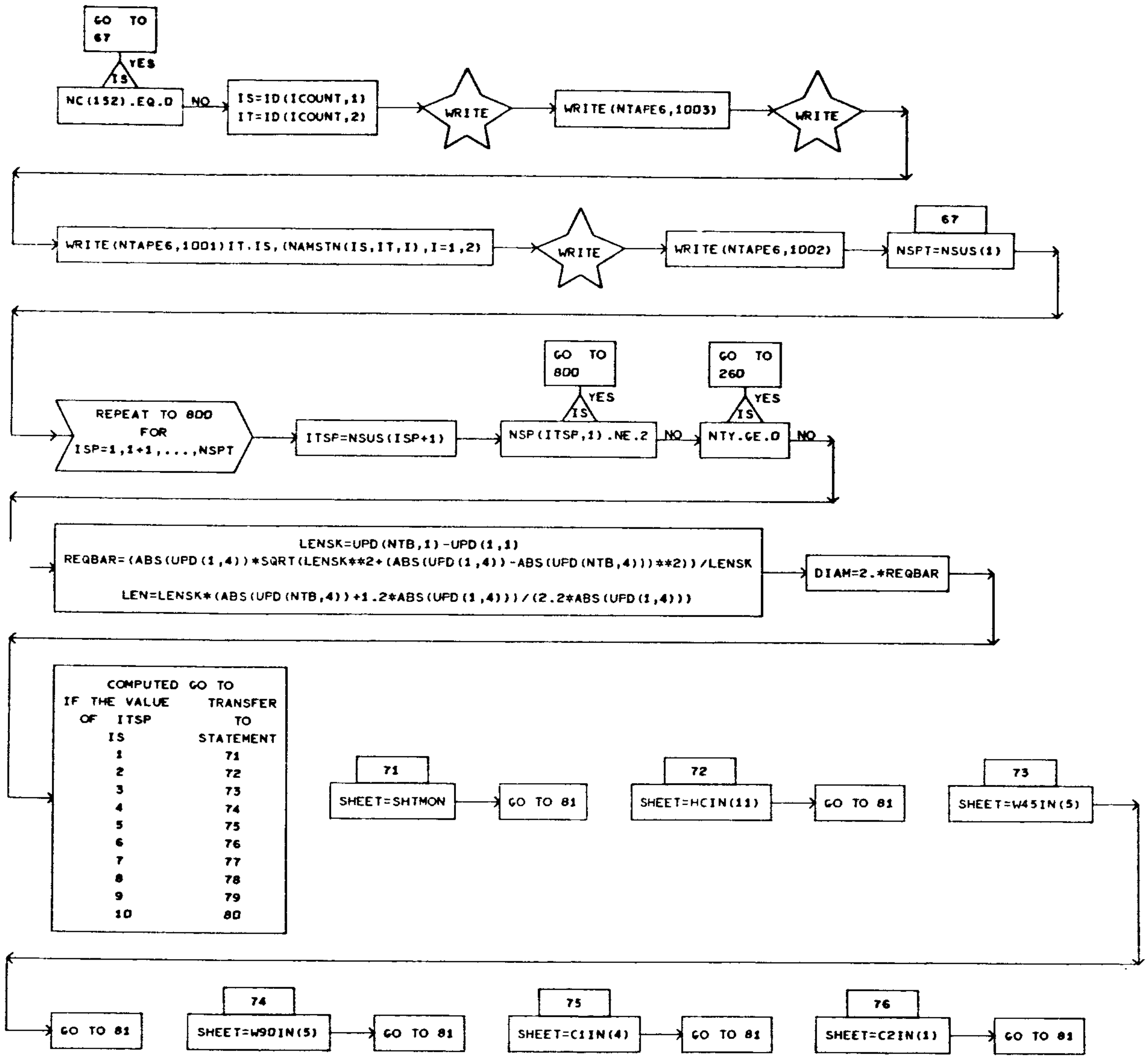


Figure 2-6. SWOP Flow Chart - LOOPP (Sheet 4 of 7)

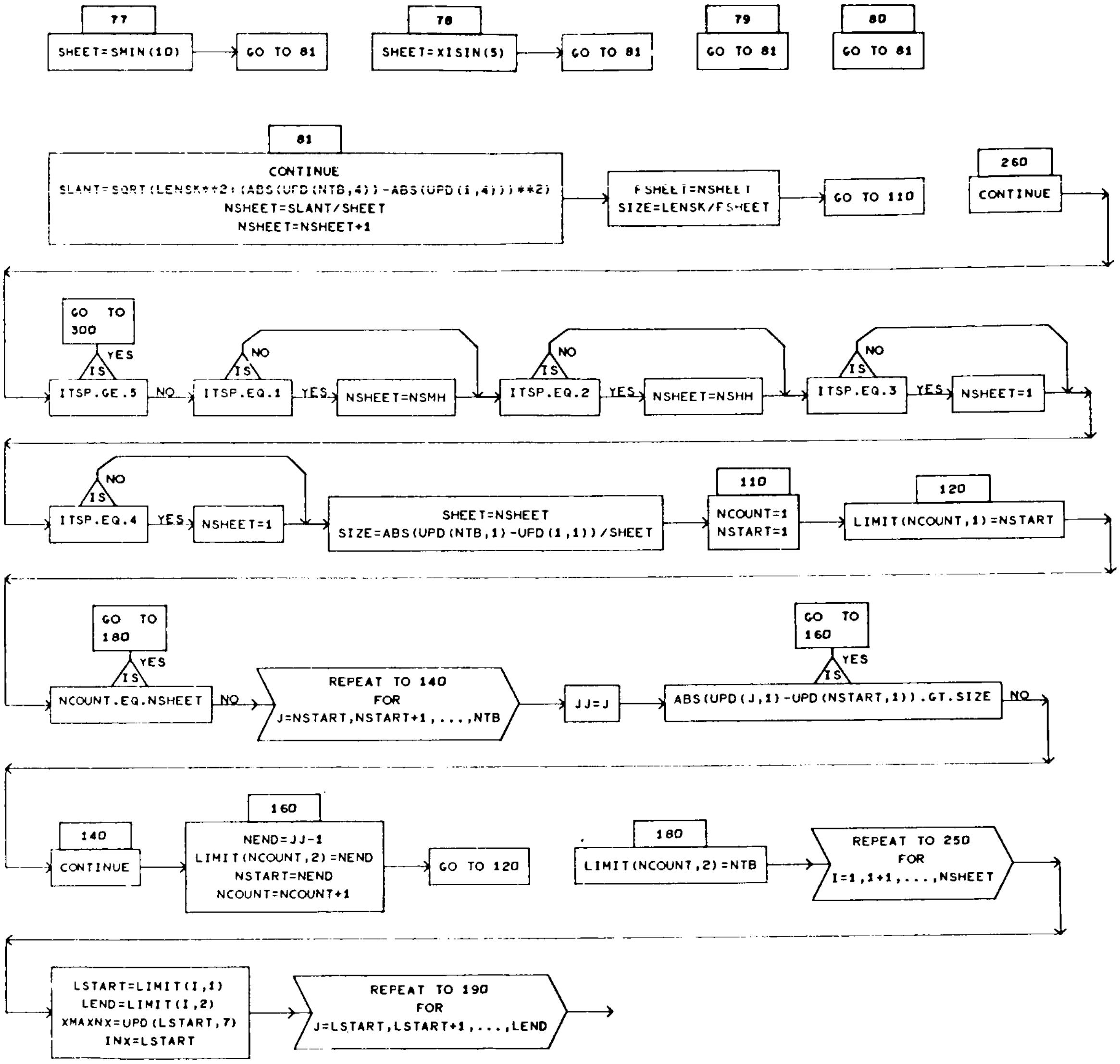


Figure 2-6. SWOP Flow Chart - LOOPP (Sheet 5 of 7)

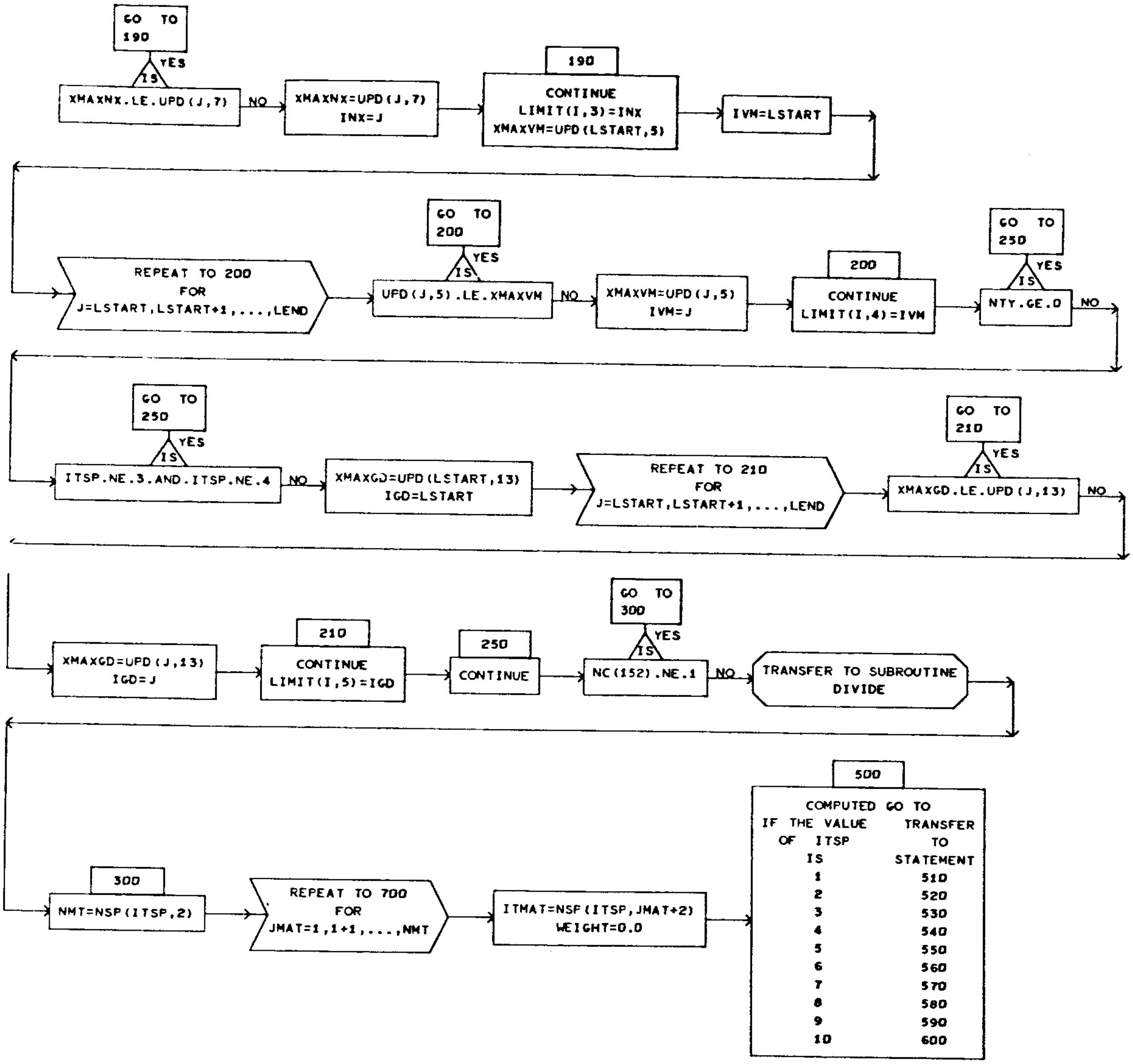


Figure 2-6. SWOP Flow Chart - LOOPP (Sheet 6 of 7)

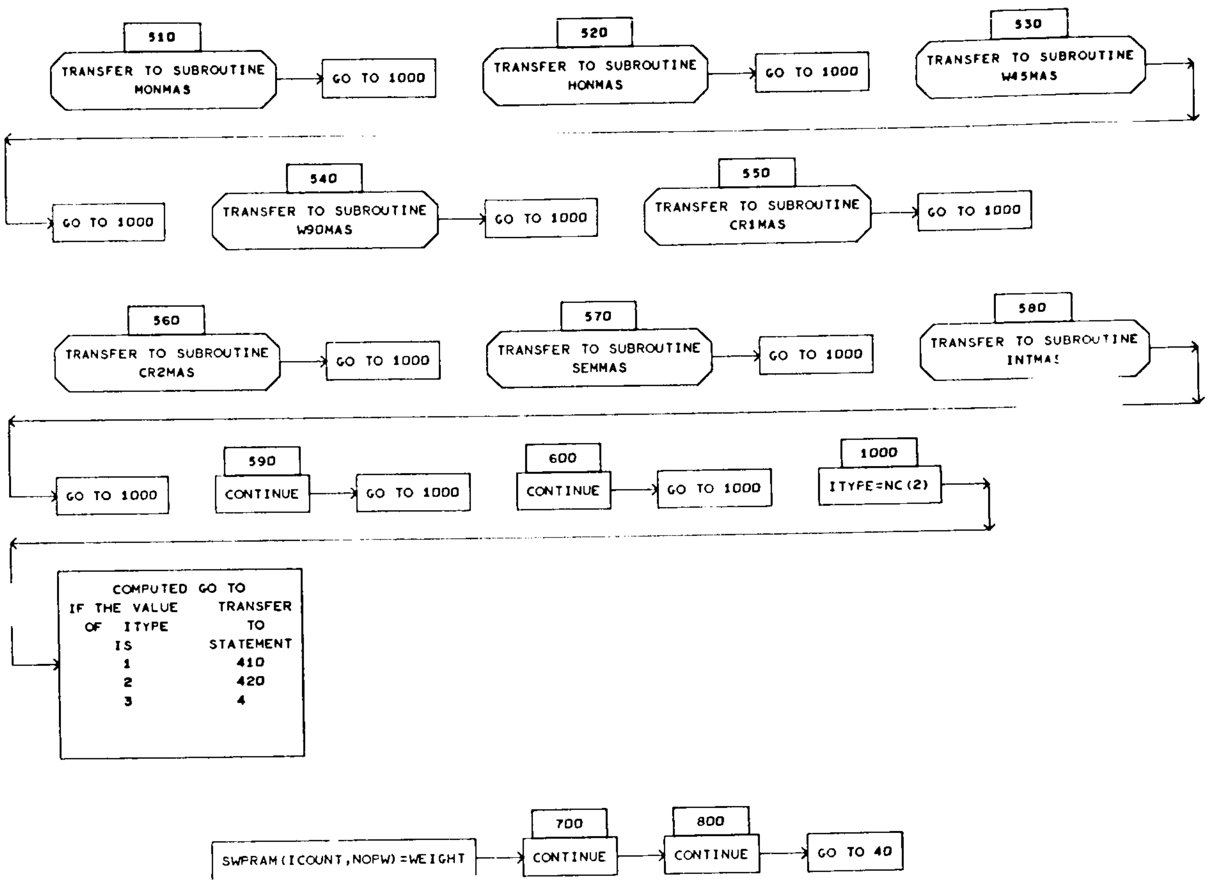


Figure 2-6. SWOP Flow Chart - LOOPP (Sheet 7 of 7)

D I M E N S I O N E D   V A R I A B L E S

SYMBOL	STORAGES	SYMBOL	STORAGES	SYMBOL	STORAGES	SYMBOL	STORAGES	SYMBOL	STORAGES
LIMIT	10,15								

Figure 2-7. SWOP Flow Chart - DIVSN (Sheet 1 of 2)

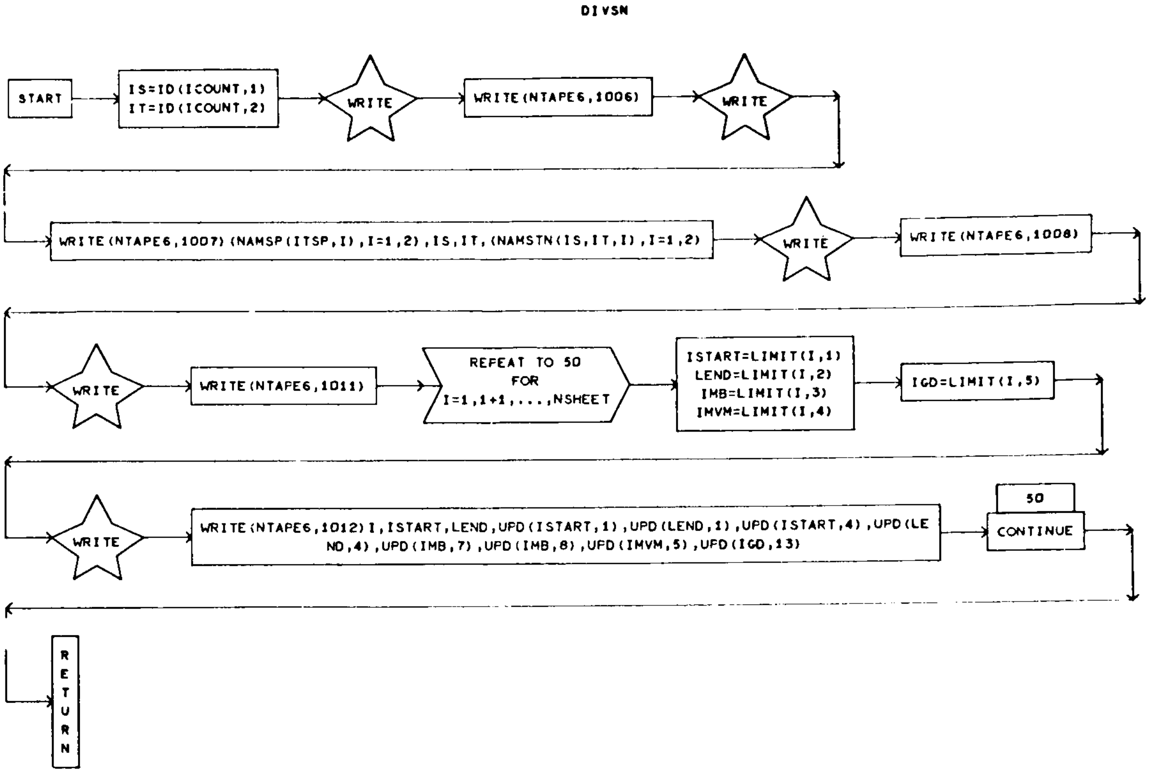


Figure 2-7. SWOP Flow Chart - DIVSN (Sheet 2 of 2)

D I M E N S I O N E D   V A R I A B L E S

SYMBOL	STORAGES	SYMBOL	STORAGES	SYMBOL	STORAGES	SYMBOL	STORAGES	SYMBOL	STORAGES
REC	5								

Figure 2-8. SWOP Flow Chart - INTRP (Sheet 1 of 2)

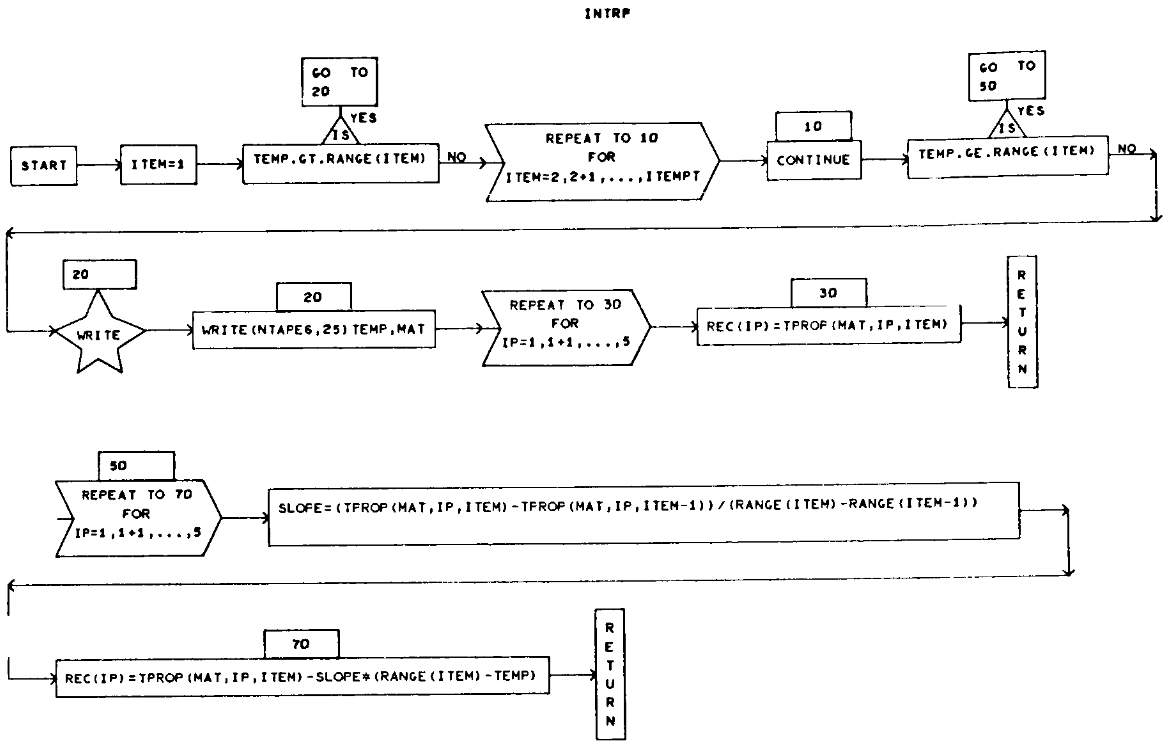


Figure 2-8. SWOP Flow Chart - INTRP (Sheet 2 of 2)

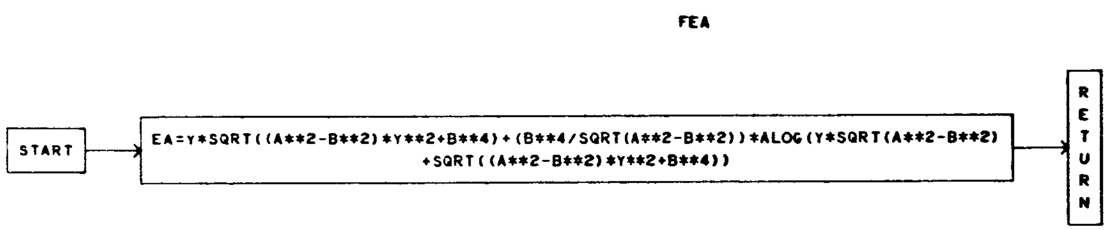


Figure 2-9. SWOP Flow Chart - FEA

SECTION 3

STRESS PROGRAM

3.1 PROGRAM DESCRIPTION

The STRESS program has been written completely in FORTRAN IV and is compatible with the IBM 7090, IBM 7040, and GE 600 series computers. The program uses an in-house input routine (READHP) which is written in both 7044 and 7094 MAP. This special input routine will have to be rewritten for the GE 600 series computer.

The general purpose of the STRESS program is to resolve the components of force and moment as applied to a beam-line structure into normal components of stress on a tank-like structure. The STRESS program will consider applied forces which are acting both externally (wind forces) and internally (gravity, gas pressures, and liquid pressures). All forces and moments are resolved pointwise in the planes of the structure's surfaces into normal stress components with one component of stress resultant (N_θ) perpendicular to the structures axis of revolution. This analysis is done timewise with only the greatest stresses retained for each of the following criteria:

a. The values of N_x and N_θ are retained which give the expression of $\sqrt{N_x^2 + N_\theta^2 - N_x N_\theta}$ the greatest algebraic value.

b. The values of N_x and N_θ are retained for the most negative values of N_x.

c. The values of N_x and N_θ are retained, which give the expression $N_x + N_\theta$ the most negative algebraic value.

Along with the above values of N_x, N_θ, and structural criteria, which are retained, the time of flight, temperature, and cause (hydrostatic or inflight) are retained for each of the above appropriate criteria for future analysis.

The types of structures, which the program is now capable of considering, are structures composed of combinations of cylinders, frustums of cones, cones, sections of spheres, and sections of ellipses of revolution, all having a common axis of revolution.

The program is entirely in single precision and the English unit system is used throughout the program.

3.2 PROGRAM ORGANIZATION

The program was written in a highly modular form in order to ease debugging problems, reduce costs, simplify the modification of the program, and simplify the understanding of the program. A large common package is used for the communication link between the program's subroutines. The following flow charts describe the program's basic, general, and detailed organization.

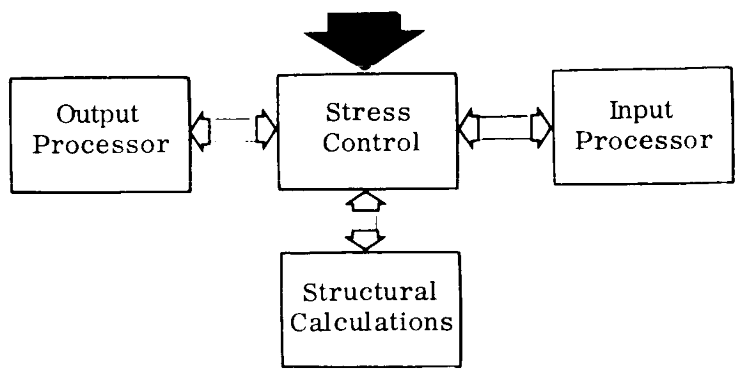


Figure 3-1. Basic Flow Chart

3.2.1 SUBROUTINES USED IN STRESS

3.2.1.1 Control Sections

a. STRESS - Controls starting, processing of input, and general logic flow of the program.

b. SFORCE - Control routine for membrane calculations.

3.2.1.2 Calculation Routines

a. ANGLE - Finds cone angles in radians.

b. DISTB - Performs membrane calculations at desired intervals on the skin of the vehicle. This routine also does hydrostatic test check when desired.

c. HYDRO - Finds hydrostatic test conditions.

d. HEADS - Performs membrane calculations at desired interval on all desired heads.

e. LEVELS - Finds liquid levels and cone angles at liquid levels for all desired tanks.

f. NSERCH - Performs a binary search of LASS 1 input for desired values.

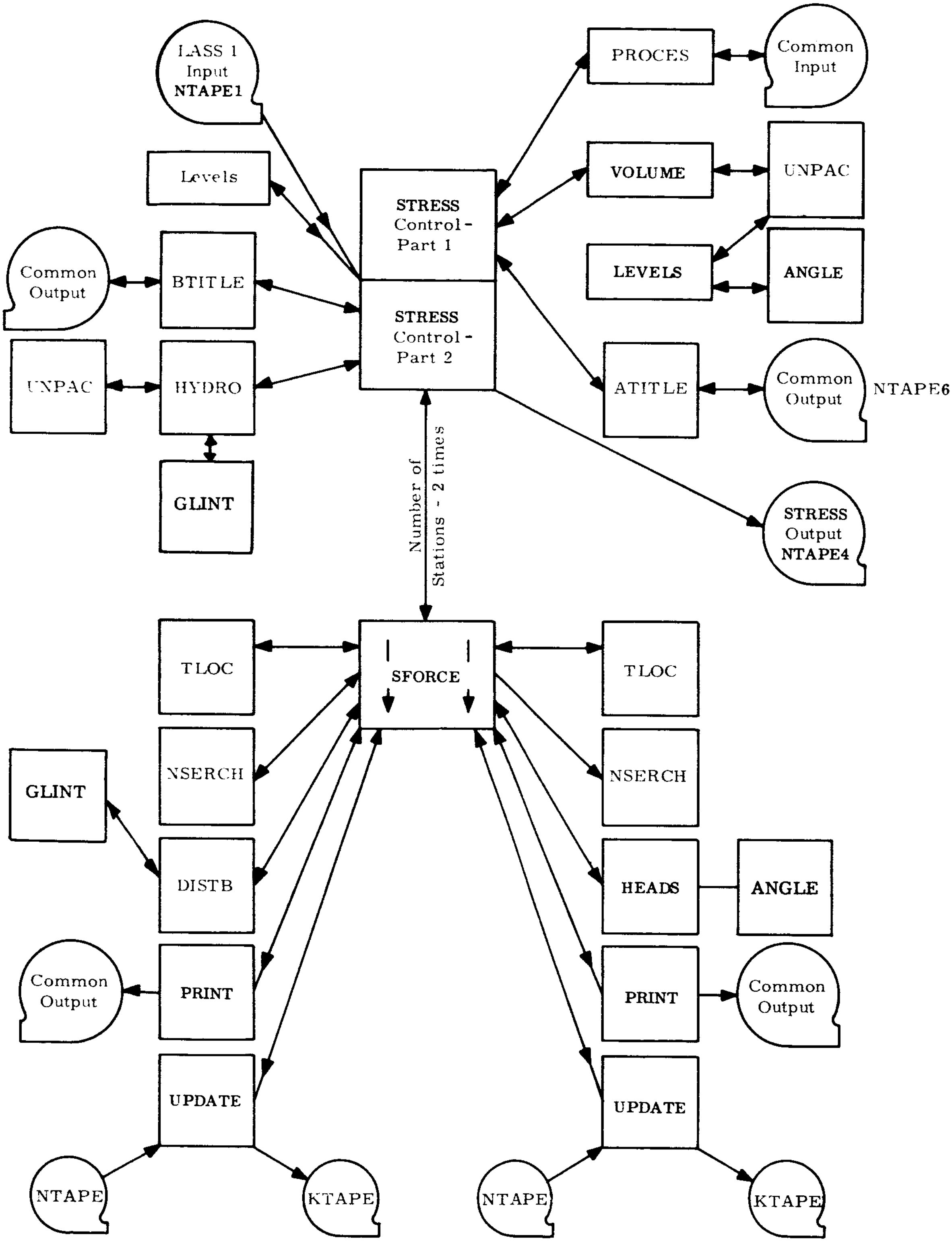


Figure 3-2. General Flow Chart

FORTRAN FLOW CHARTS OF THE STRESS PROGRAM

D I M E N S I O N E D   V A R I A B L E S

SYMBOL	STORAGES	SYMBOL	STORAGES	SYMBOL	STORAGES	SYMBOL	STORAGES	SYMBOL	STORAGES
SAVE	40	NSAVE	40	FEST	10	LPHASE	10		

Figure 3-3. Flow Chart of Stress Program (Sheet 1 of 9)

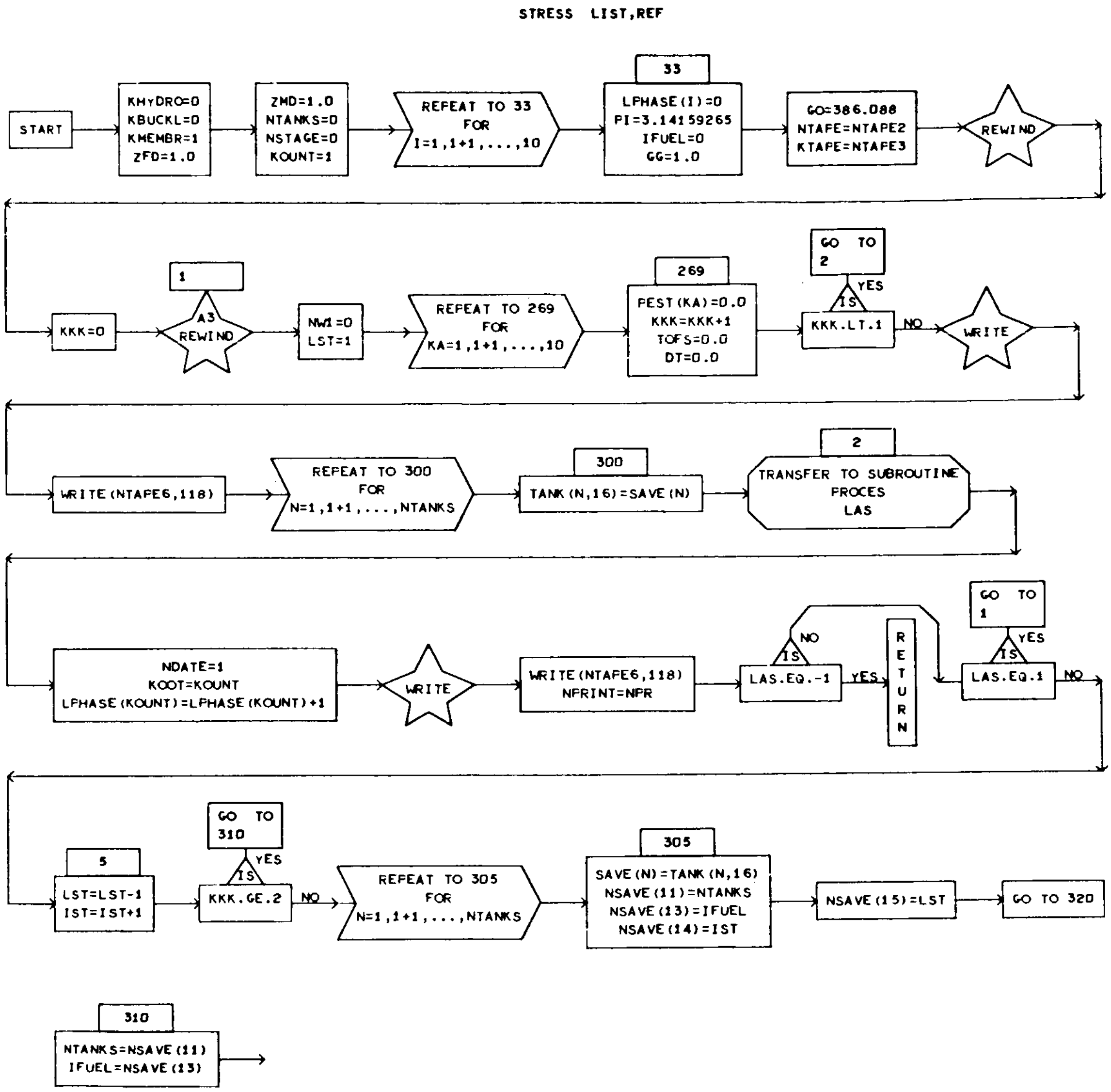


Figure 3-3. Flow Chart of Stress Program (Sheet 2 of 9)

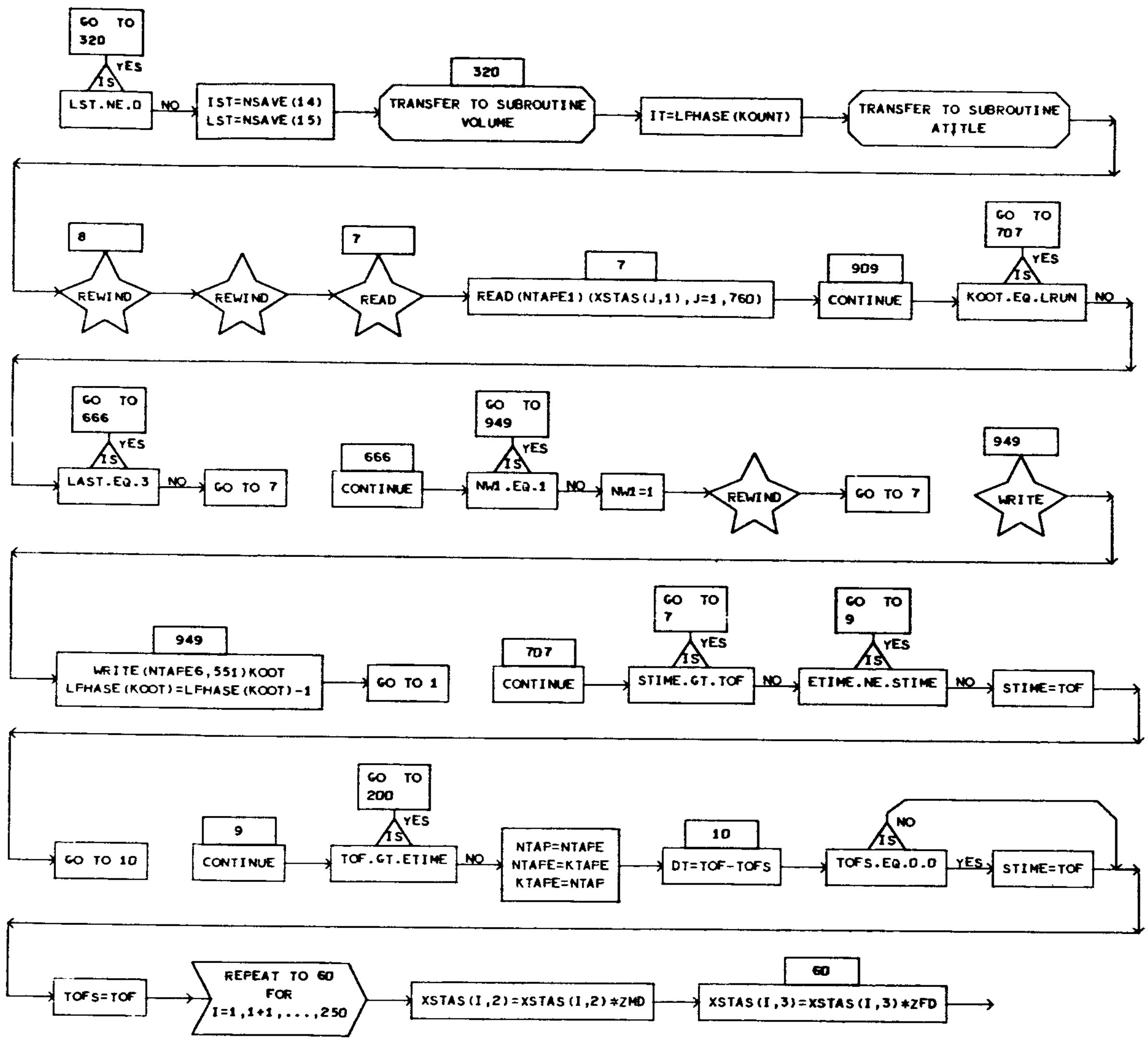


Figure 3-3. Flow Chart of Stress Program (Sheet 3 of 9)

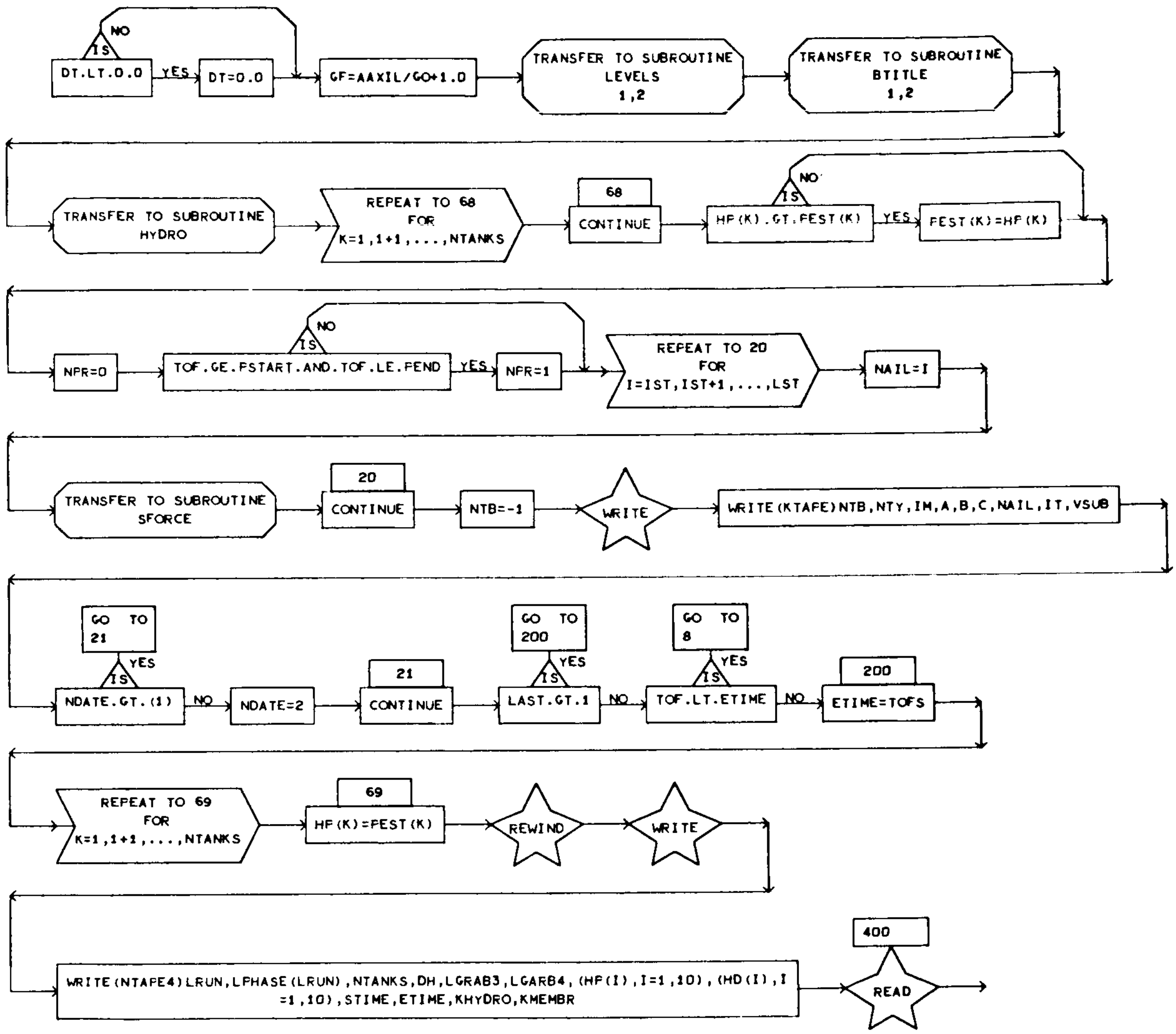


Figure 3-3. Flow Chart of Stress Program (Sheet 4 of 9)

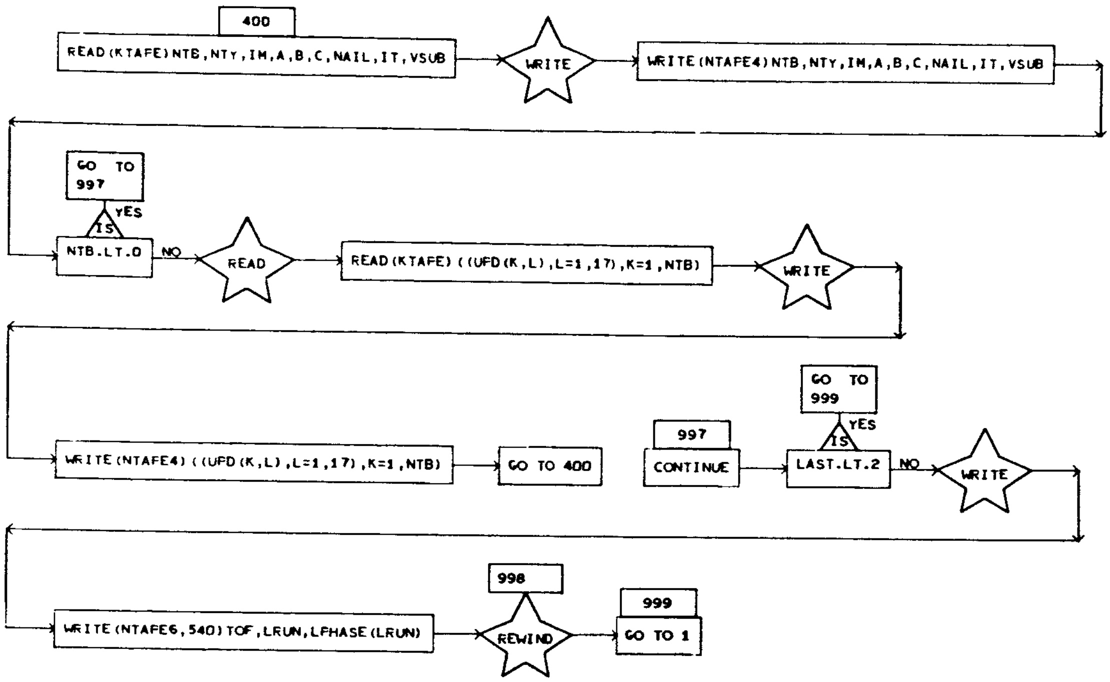


Figure 3-3. Flow Chart of Stress Program (Sheet 5 of 9)

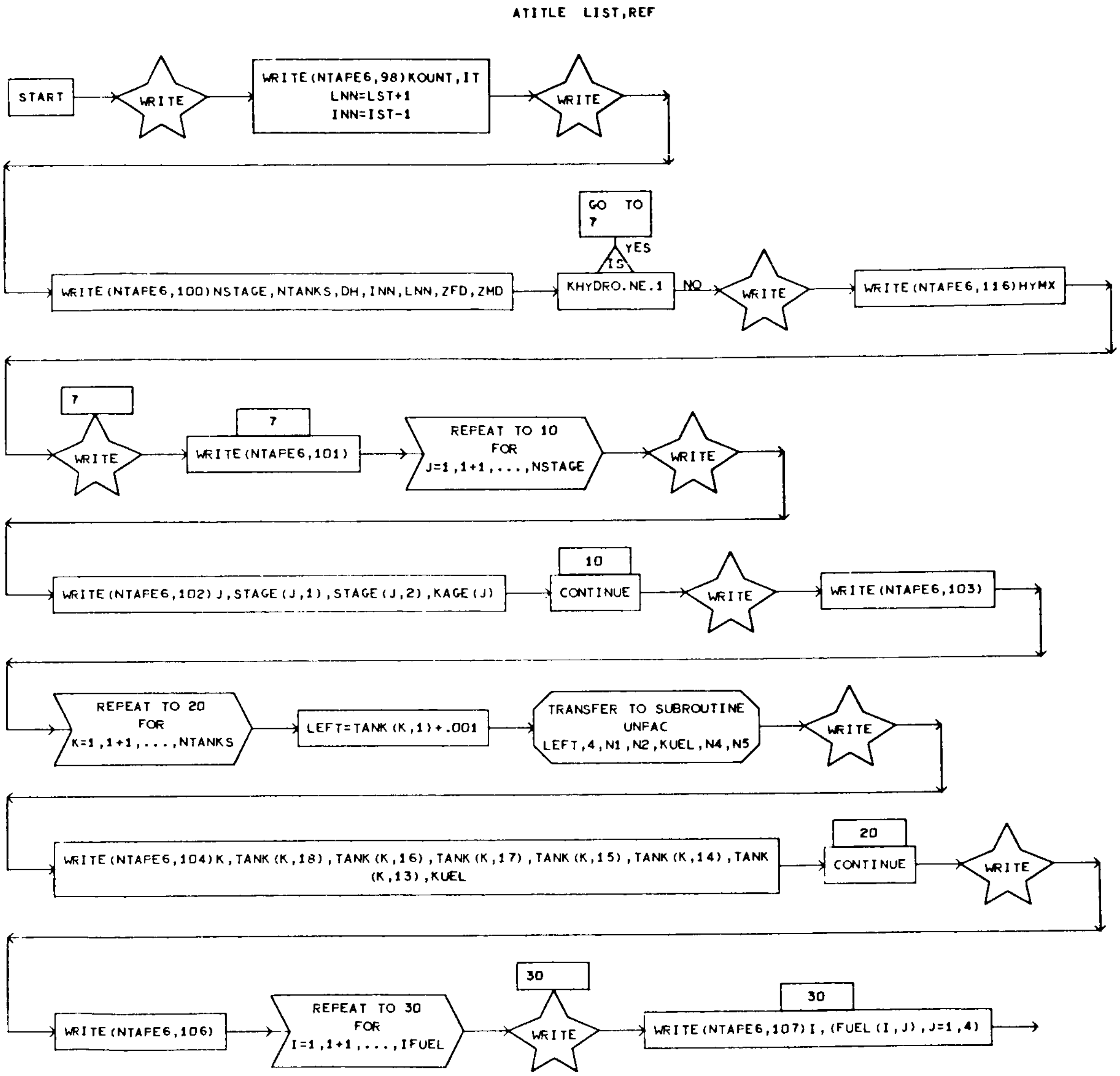


Figure 3-3. Flow Chart of Stress Program (Sheet 6 of 9)

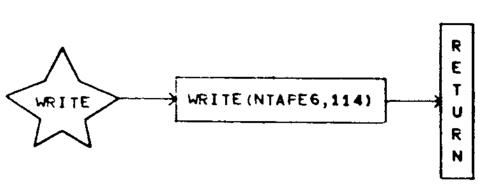


Figure 3-3. Flow Chart of Stress Program (Sheet 7 of 9)

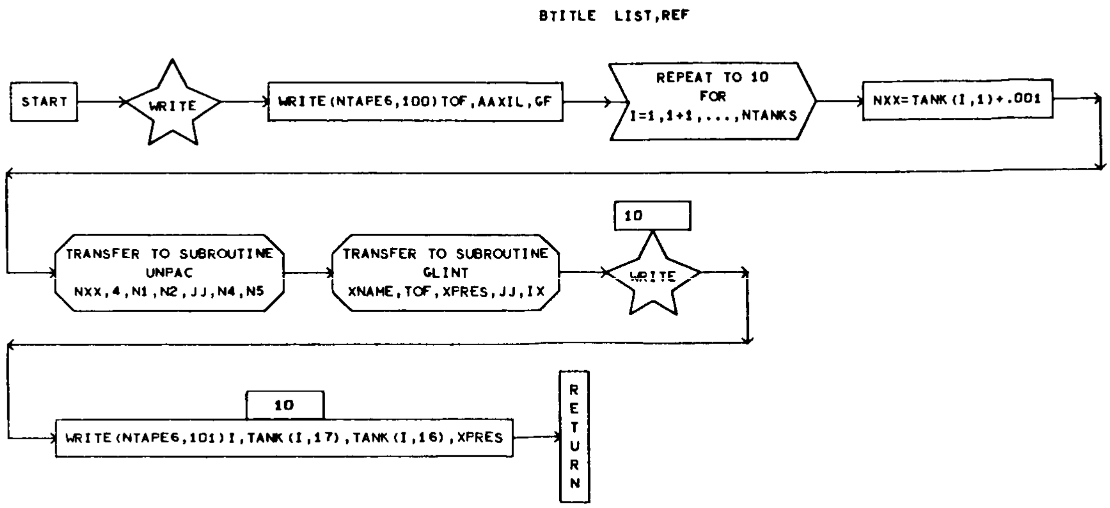


Figure 3-3. Flow Chart of Stress Program (Sheet 8 of 9)

ANGLE LIST,REF

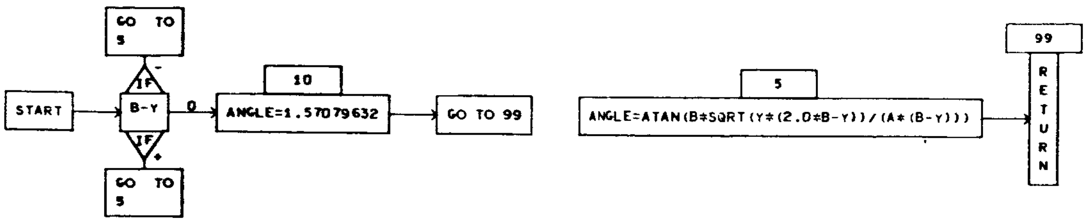


Figure 3-3. Flow Chart of Stress Program (Sheet 9 of 9)

DIMENSIONED VARIABLES

SYMBOL	STORAGES	SYMBOL	STORAGES	SYMBOL	STORAGES	SYMBOL	STORAGES	SYMBOL	STORAGES
BCD	2	M	100						

Figure 3-4. Subroutine Flow Charts, GLINT3, DISTB, HEADS, HYDRO, LEVELS, NSERCH, and PRINT (Sheet 1 of 13)

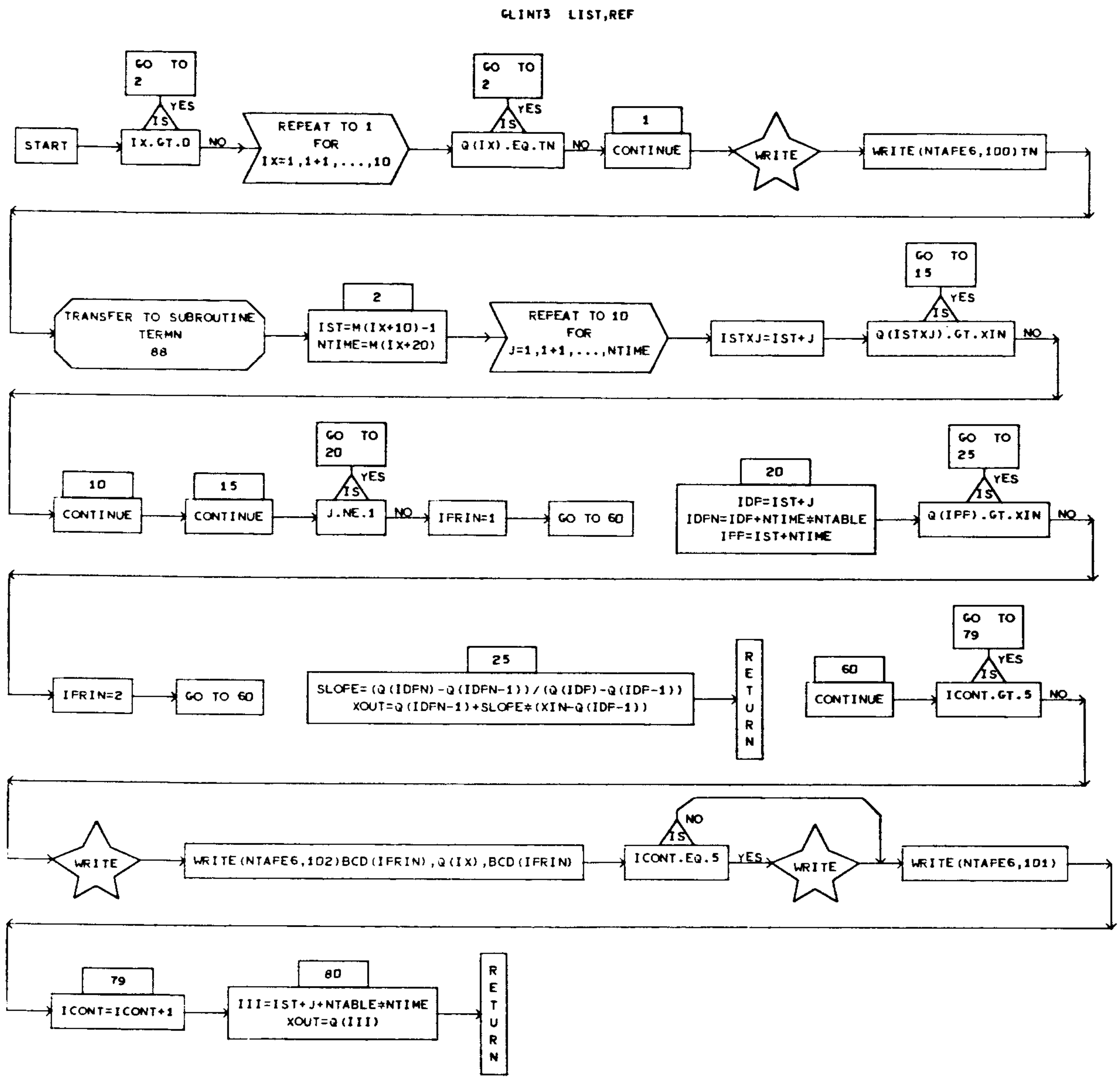


Figure 3-4. Subroutine Flow Charts, GLINT3, DISTB, HEADS, HYDRO, LEVELS, NSERCH, and PRINT (Sheet 2 of 13)

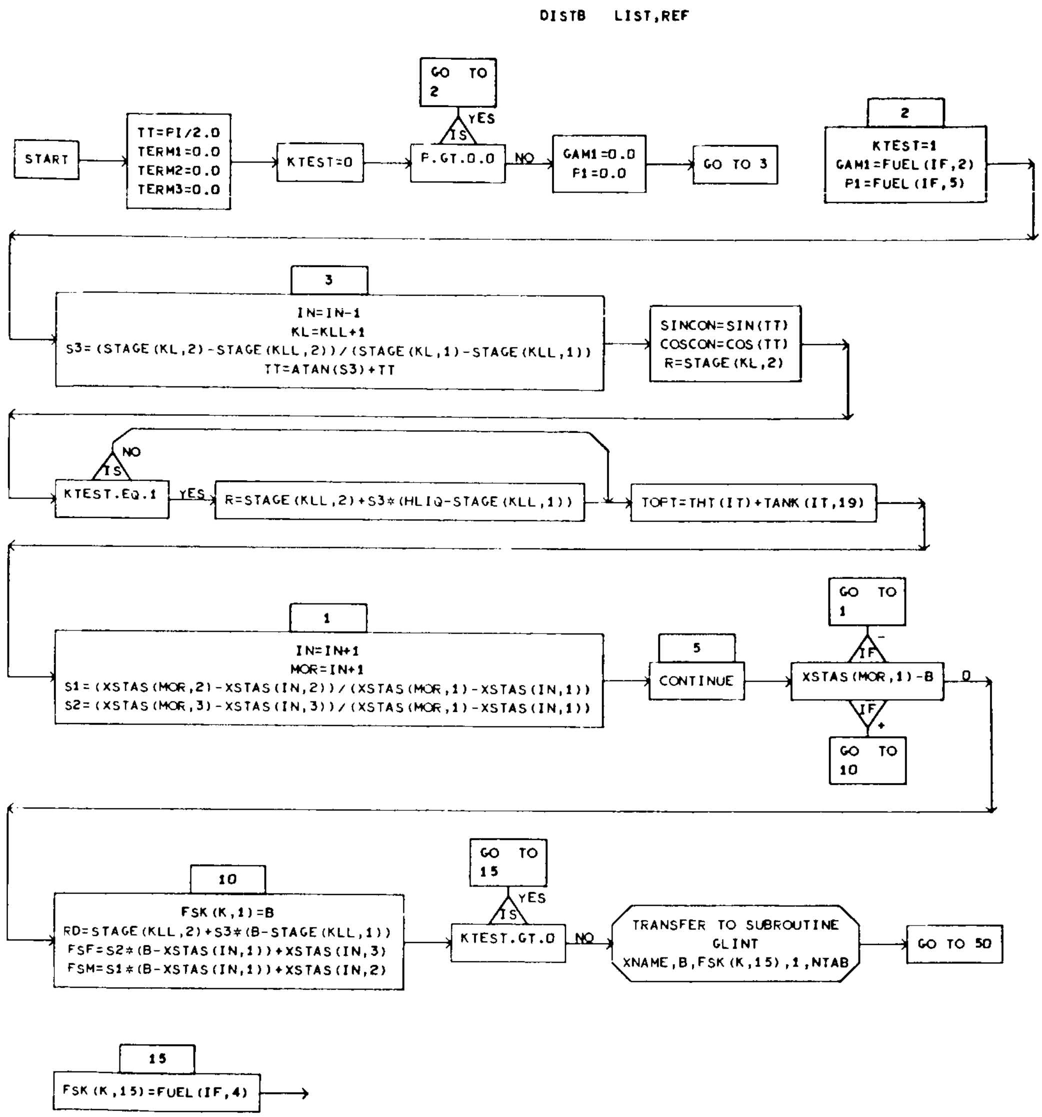


Figure 3-4. Subroutine Flow Charts, GLINT3, DISTB, HEADS, HYDRO, LEVELS, NSERCH, and PRINT (Sheet 3 of 13)

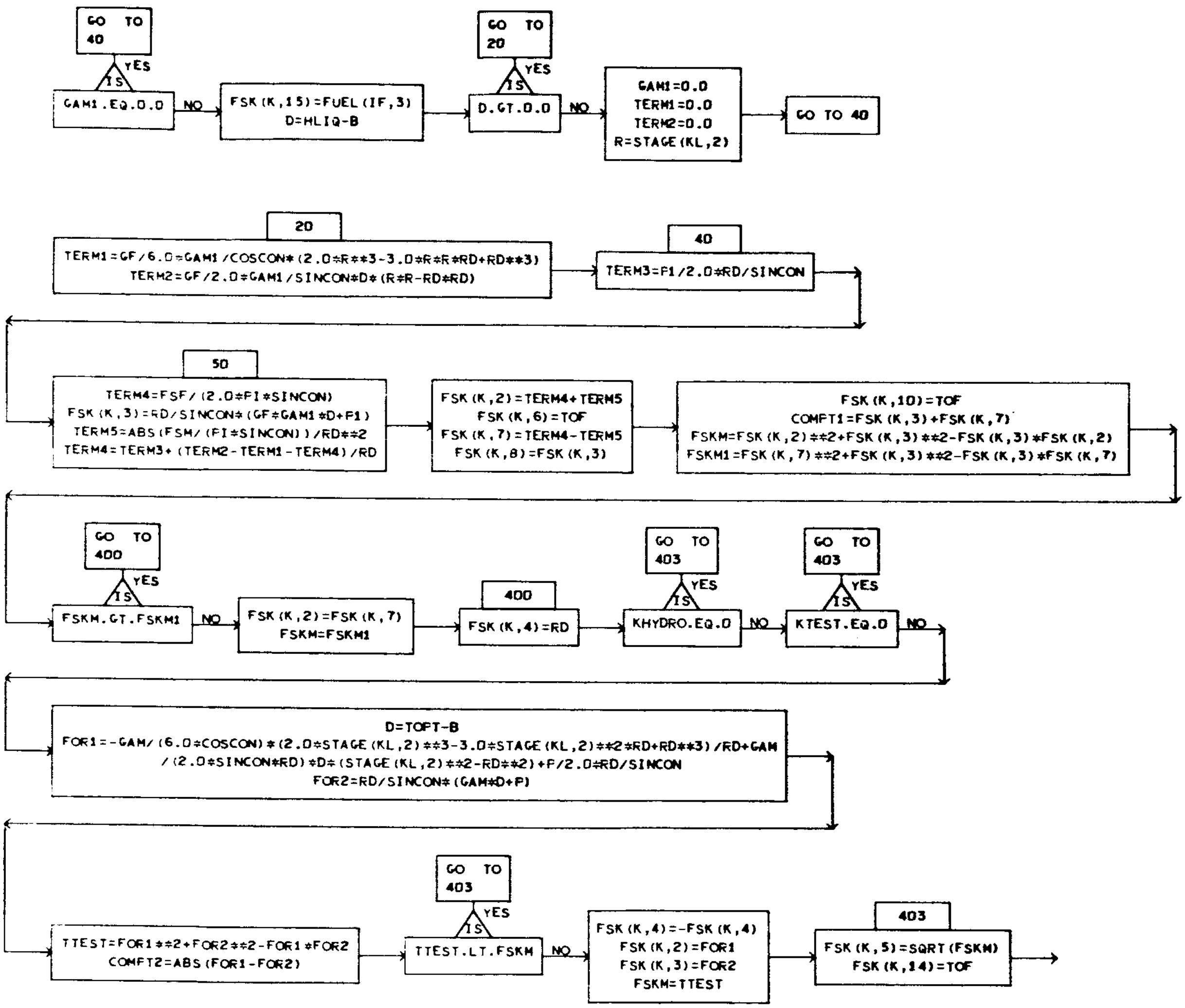
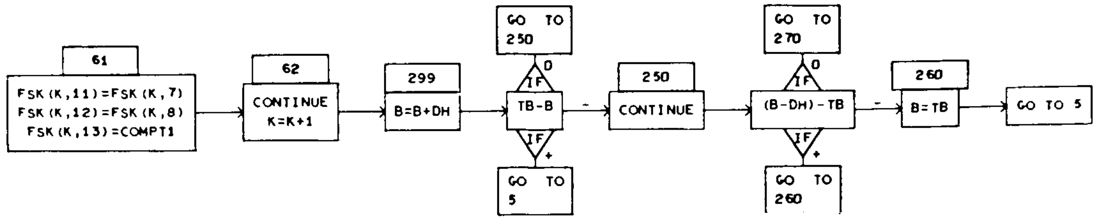


Figure 3-4. Subroutine Flow Charts, GLINT3, DISTB, HEADS, HYDRO, LEVELS, NSERCH, and PRINT (Sheet 4 of 13)



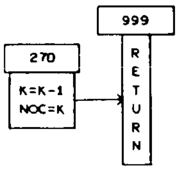


Figure 3-4. Subroutine Flow Charts, GLINT3, DISTB, HEADS, HYDRO, LEVELS, NSERCH, and PRINT (Sheet 5 of 13)

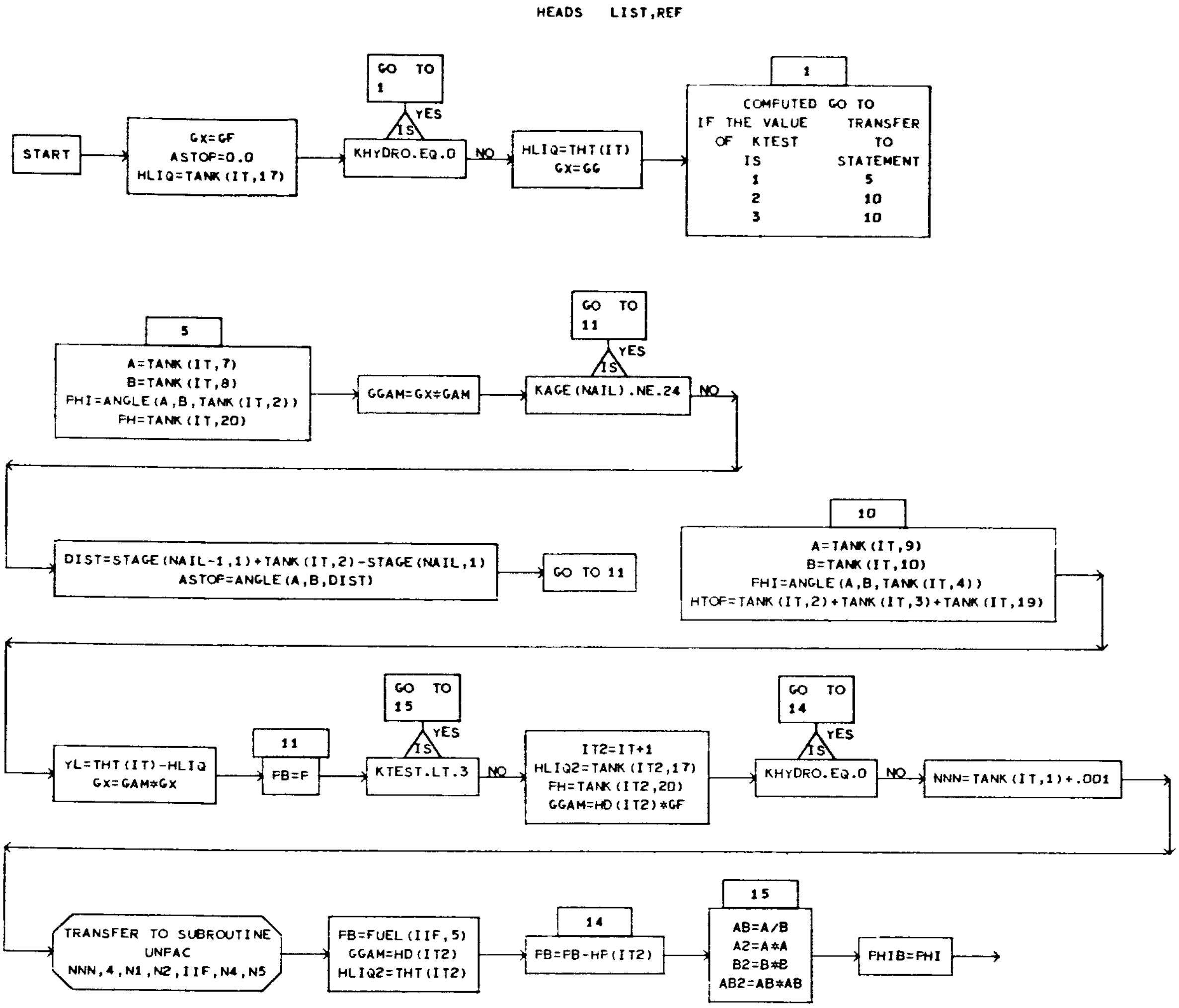


Figure 3-4. Subroutine Flow Charts, GLINT3, DISTB, HEADS, HYDRO, LEVELS, NSERCH, and PRINT (Sheet 6 of 13)

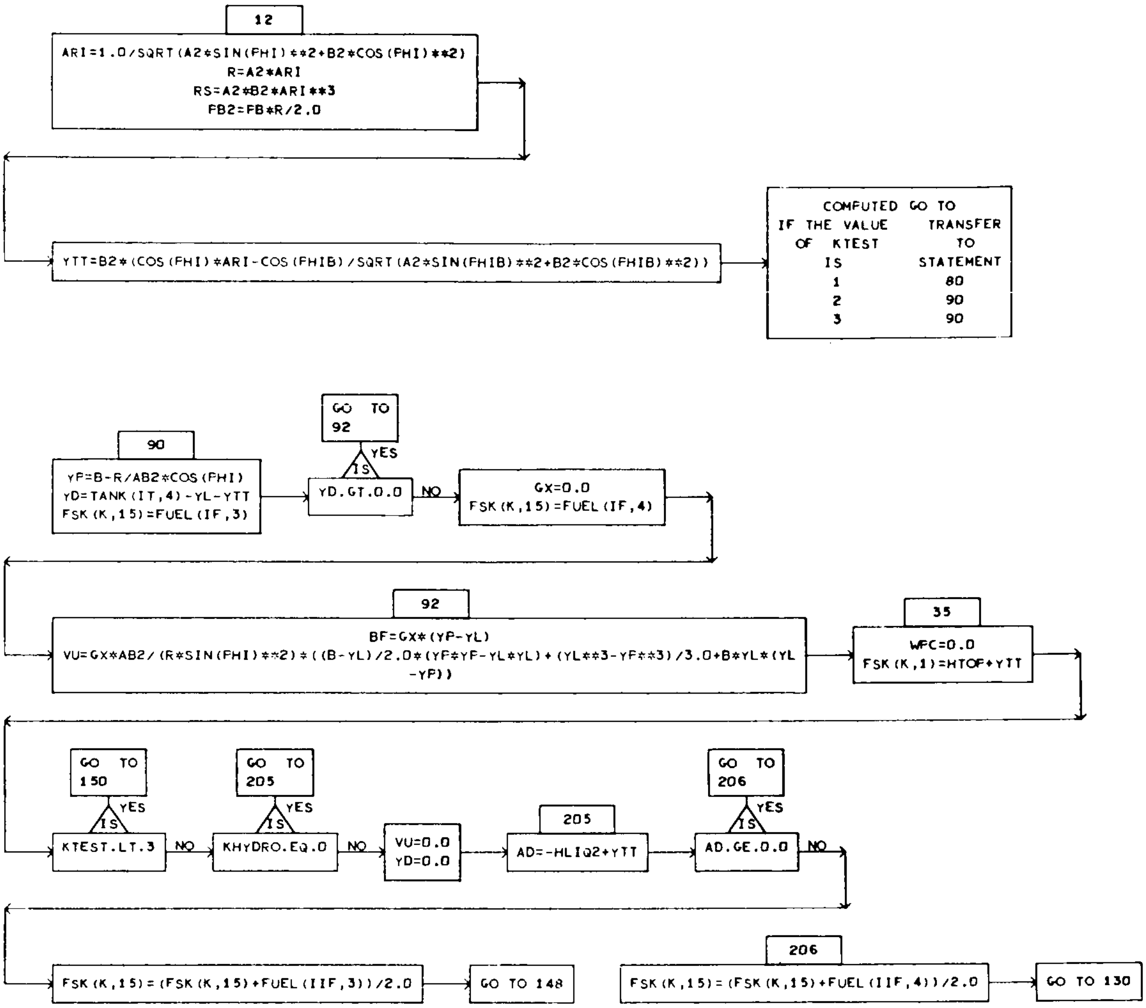


Figure 3-4. Subroutine Flow Charts, GLINT3, DISTB, HEADS, HYDRO, LEVELS, NSERCH, and PRINT (Sheet 7 of 13)

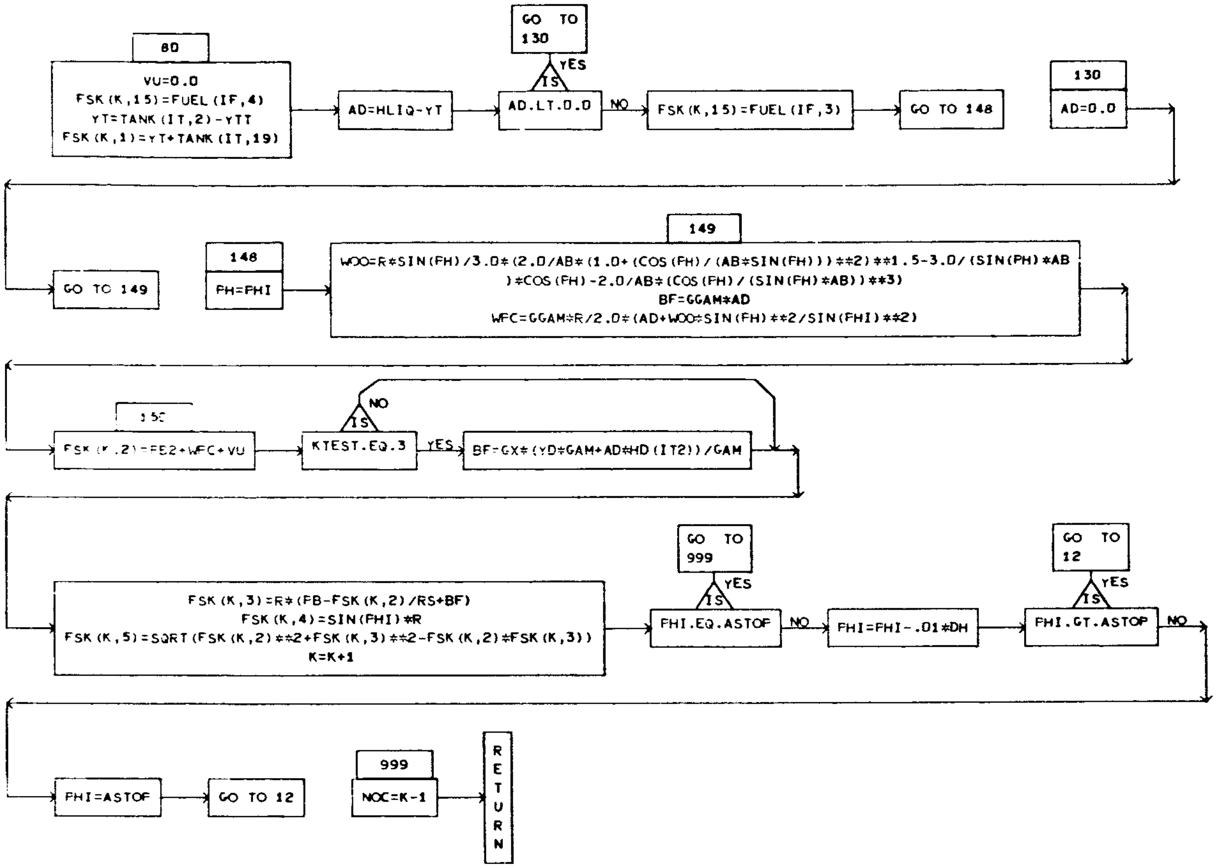


Figure 3-4. Subroutine Flow Charts, GLINT3, DISTB, HEADS, HYDRO, LEVELS, NSERCH, and PRINT (Sheet 8 of 13)

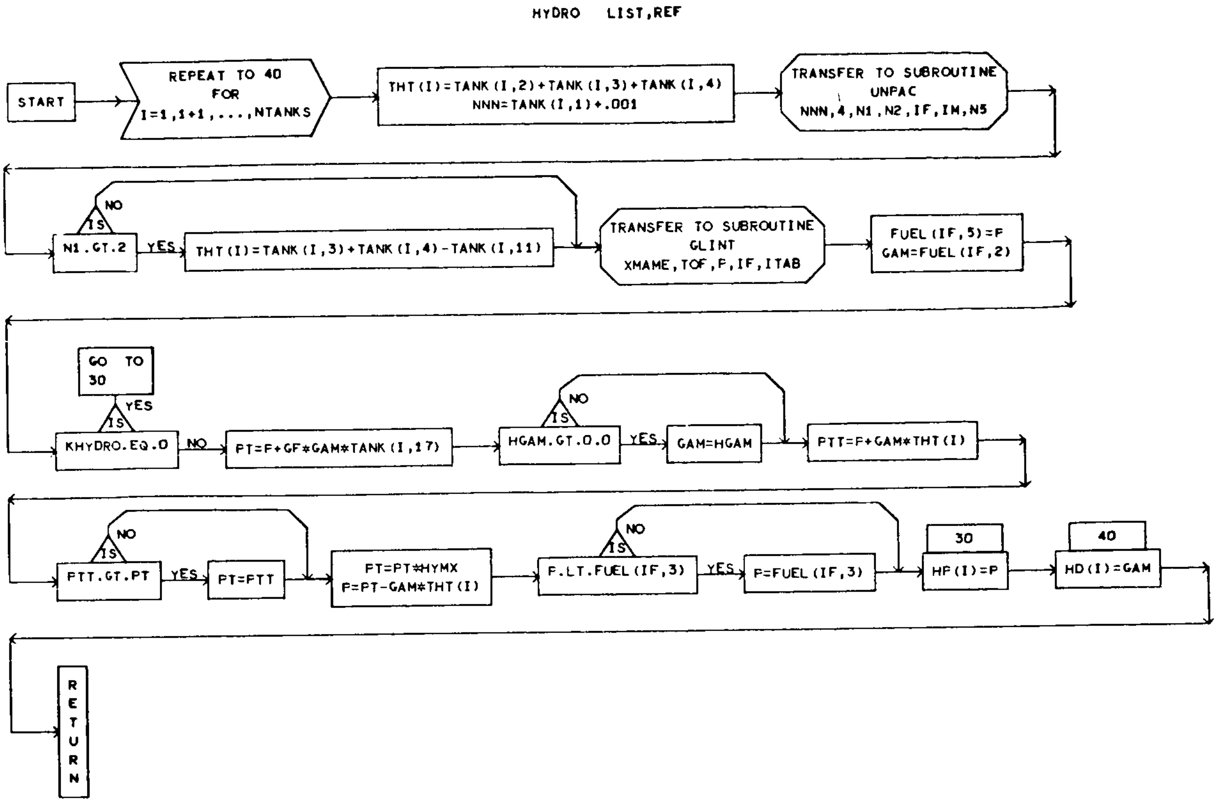


Figure 3-4. Subroutine Flow Charts, GLINT3, DISTB, HEADS, HYDRO, LEVELS, NSERCH, and PRINT (Sheet 9 of 13)

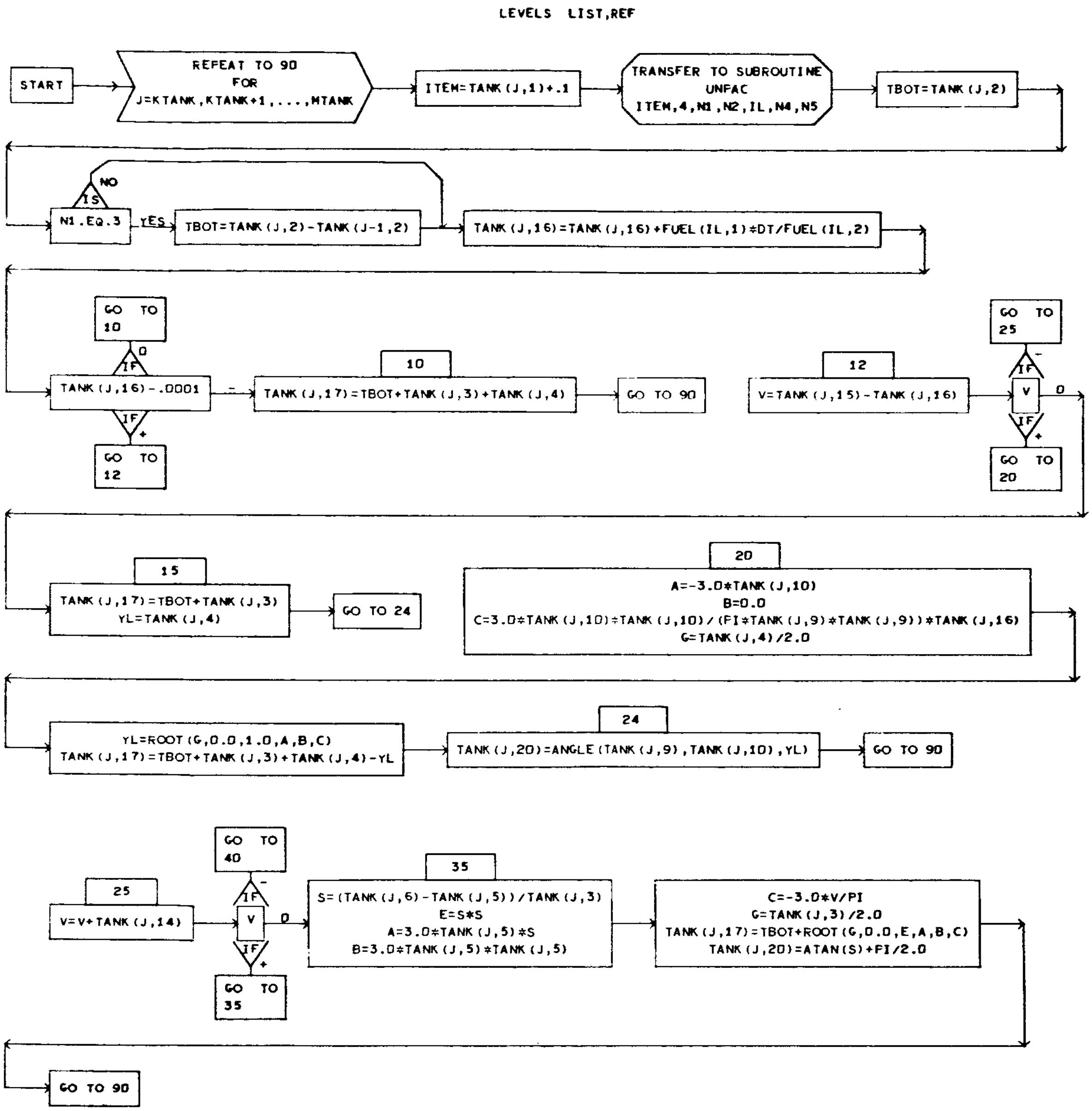


Figure 3-4. Subroutine Flow Charts, GLINT3, DISTB, HEADS, HYDRO, LEVELS, NSERCH, and PRINT (Sheet 10 of 13)

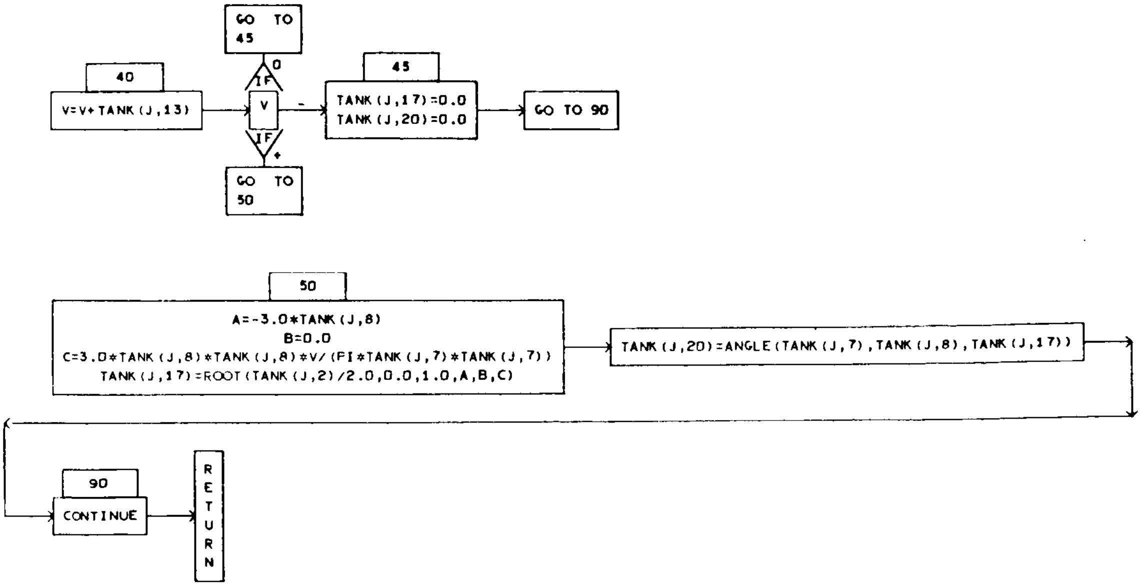


Figure 3-4. Subroutine Flow Charts, GLINT3, DISTB, HEADS, HYDRO, LEVELS, NSERCH, and PRINT (Sheet 11 of 13)

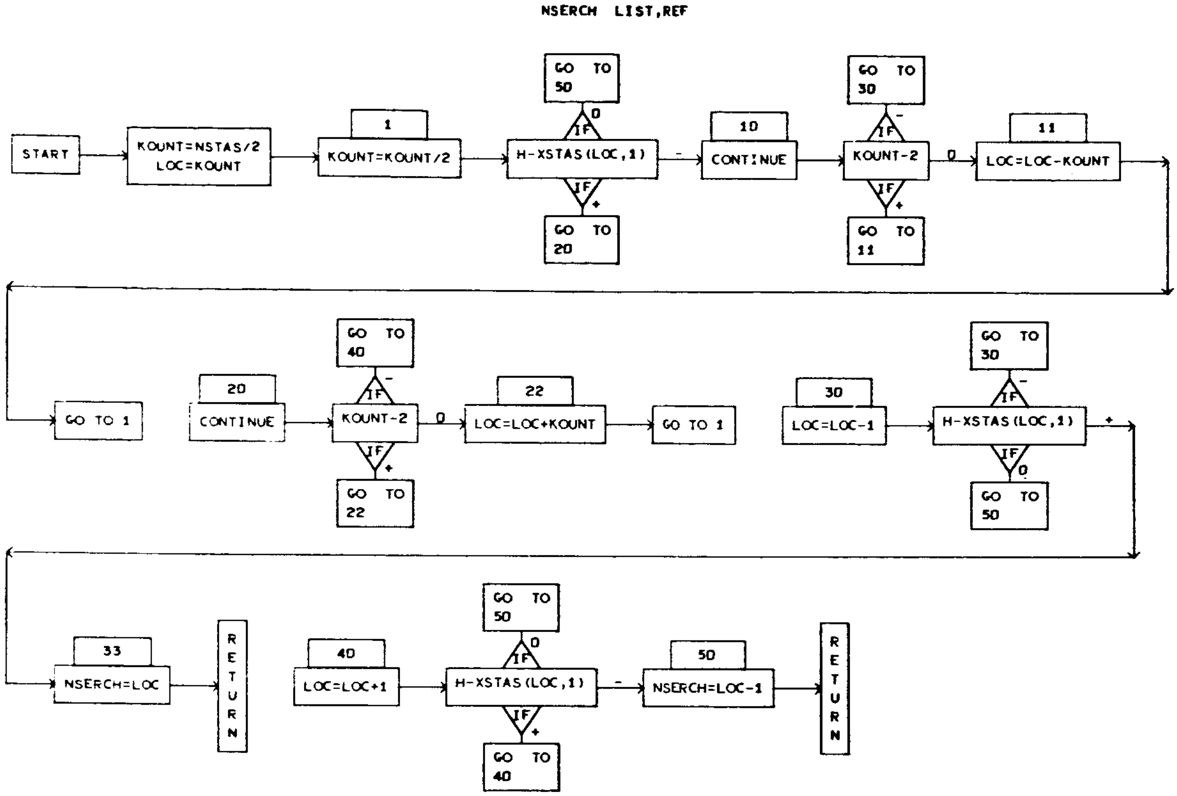


Figure 3-4. Subroutine Flow Charts, GLINT3, DISTB, HEADS, HYDRO, LEVELS, NSERCH, and PRINT (Sheet 12 of 13)

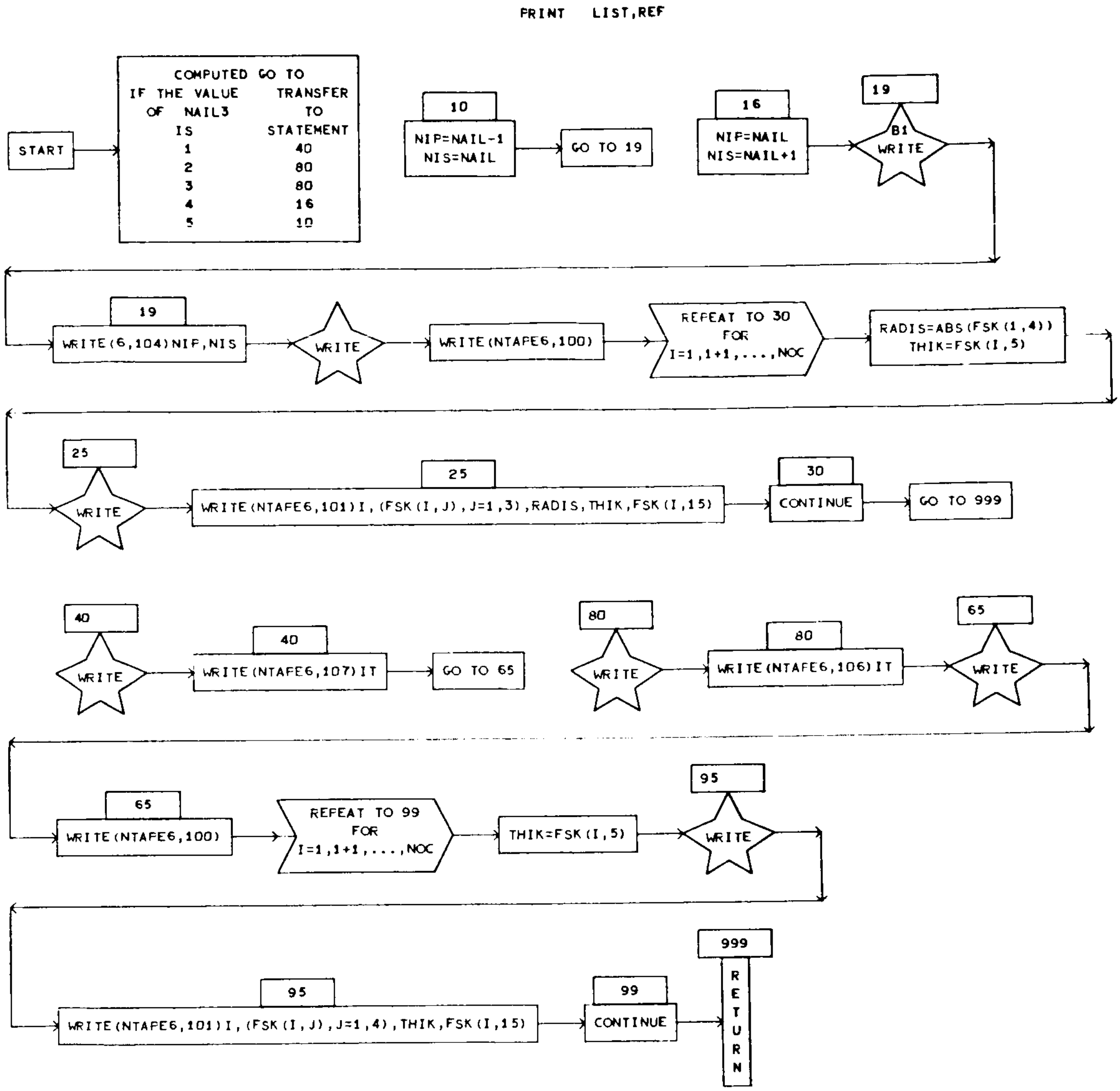


Figure 3-4. Subroutine Flow Charts, GLINT3, DISTB, HEADS, HYDRO, LEVELS, NSERCH, and PRINT (Sheet 13 of 13)

D I M E N S I O N E D   V A R I A B L E S

SYMBOL	STORAGES	SYMBOL	STORAGES	SYMBOL	STORAGES	SYMBOL	STORAGES	SYMBOL	STORAGES
CARD	10	DATA	41	IDATA	41	NALYS	5		

Figure 3-5. Subroutine Flow Charts, PROCES, ROOT, SFORCE, TERMN, and TLOC (Sheet 1 of 8)

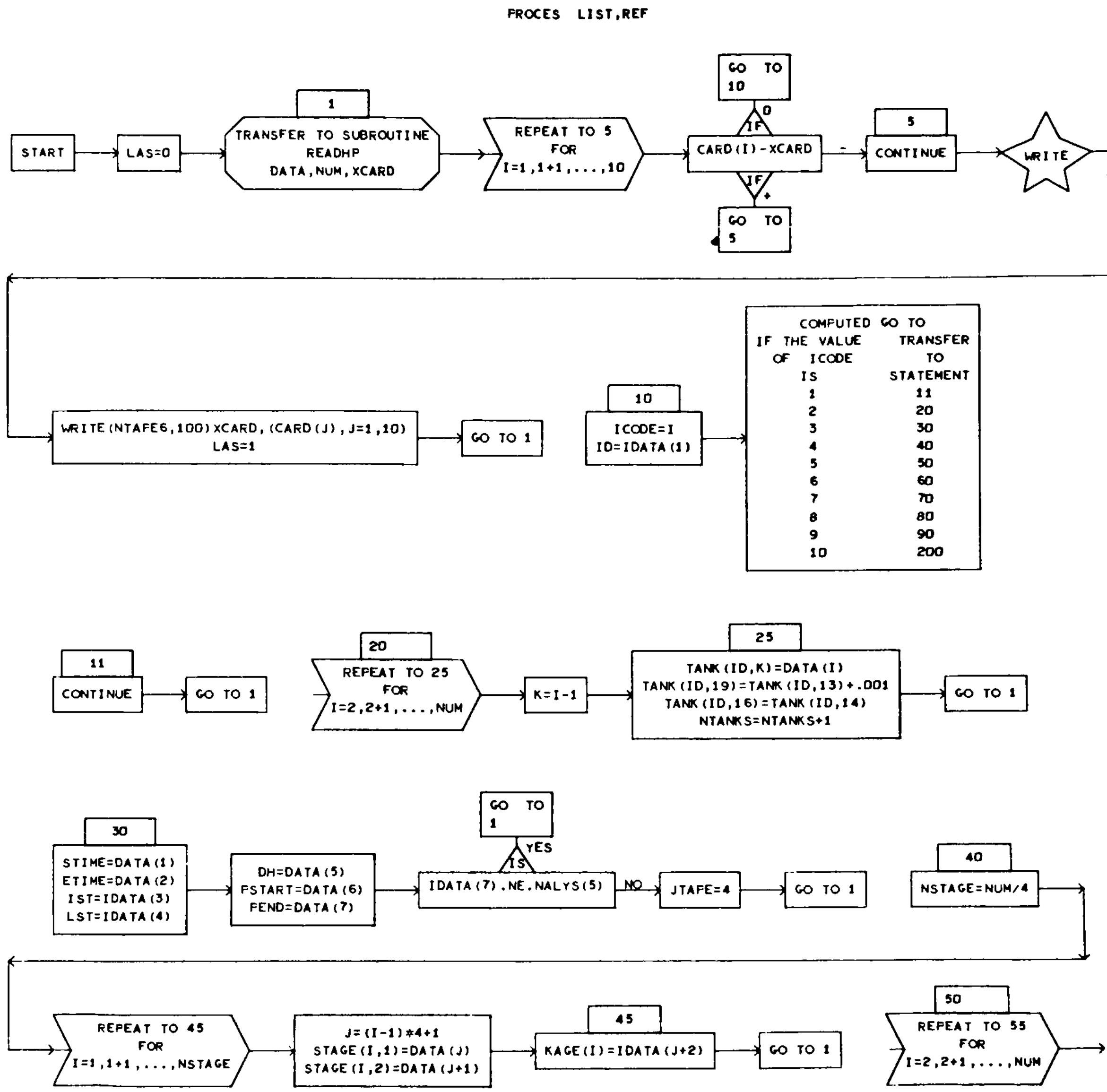


Figure 3-5. Subroutine Flow Charts, PROCES, ROOT, SFORCE, TERMN, and TLOC (Sheet 2 of 8)

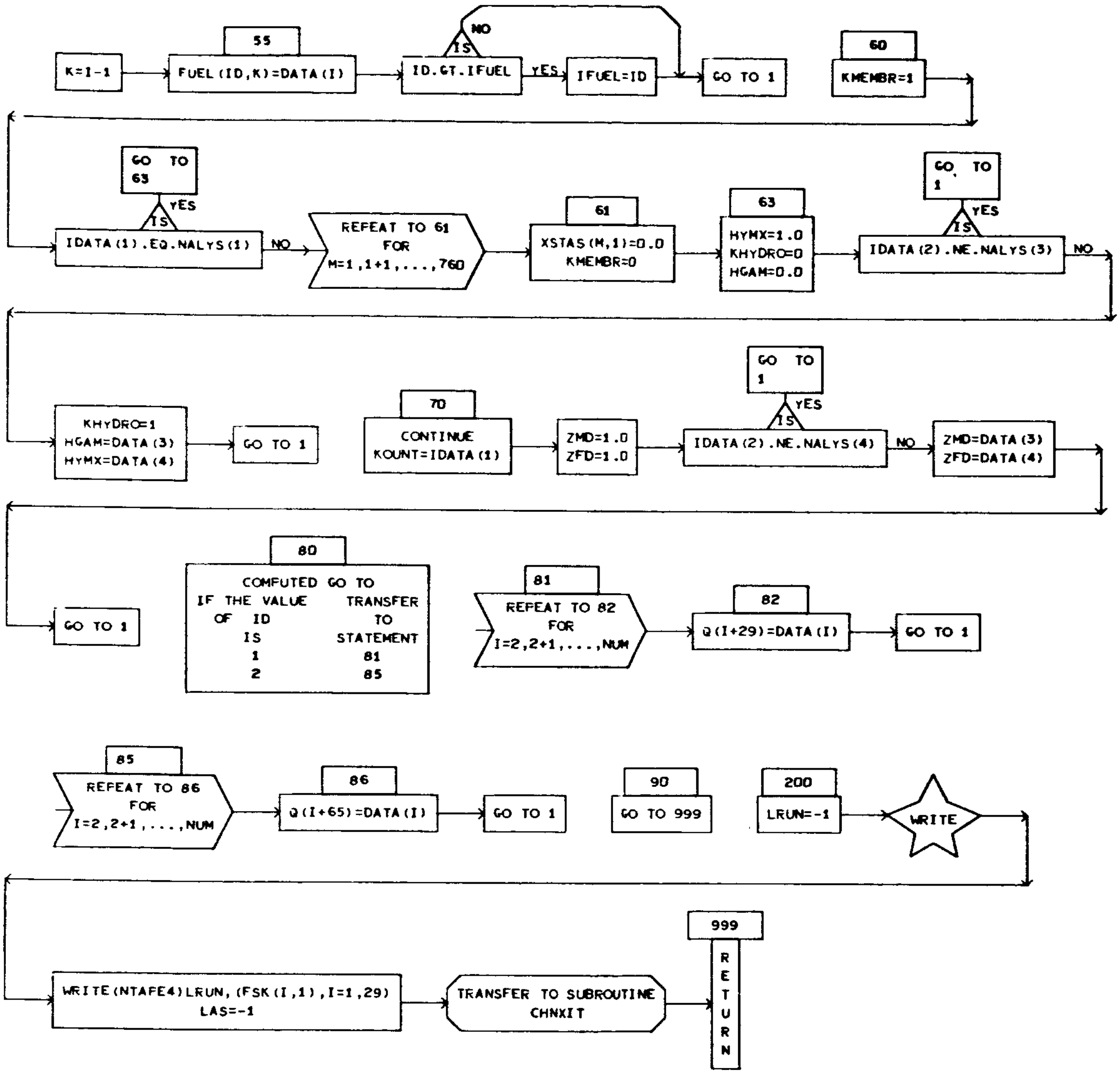


Figure 3-5. Subroutine Flow Charts, PROCES, ROOT, SFORCE, TERMN, and TLOC (Sheet 3 of 8)

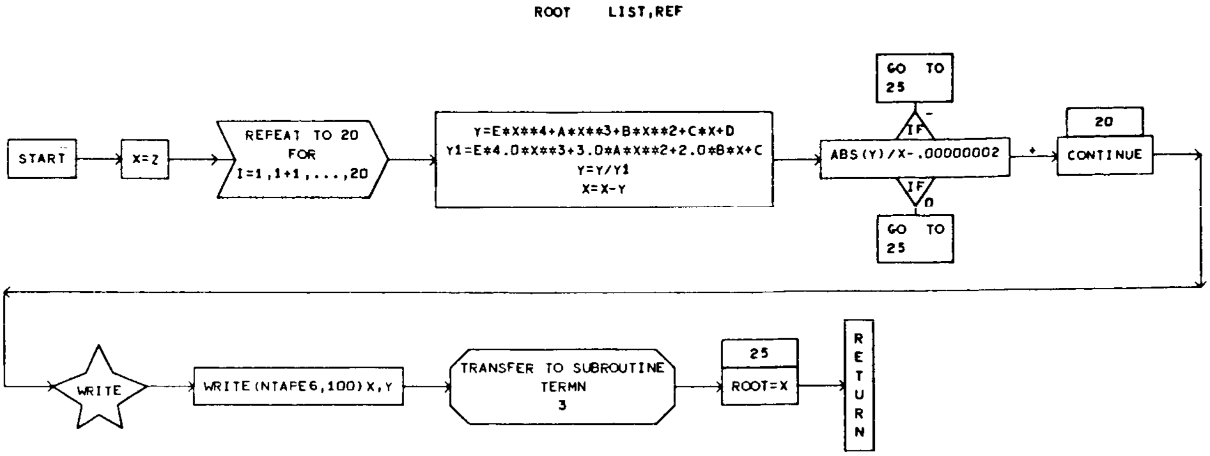


Figure 3-5. Subroutine Flow Charts, PROCES, ROOT, SFORCE, TERMN, and TLOC (Sheet 4 of 8)

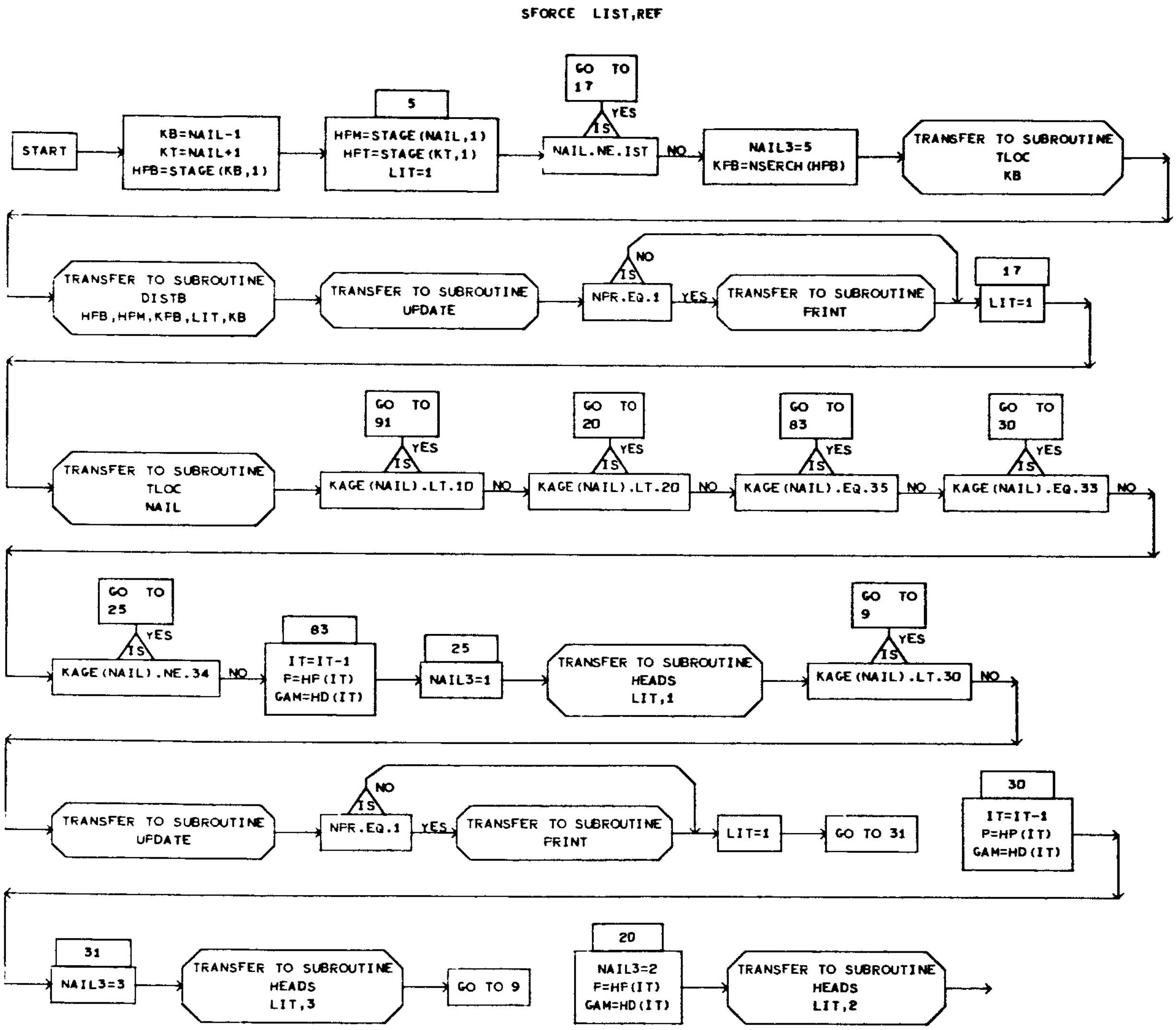


Figure 3-5. Subroutine Flow Charts, PROCES, ROOT, SFORCE, TERMN, and TLOC (Sheet 5 of 8)

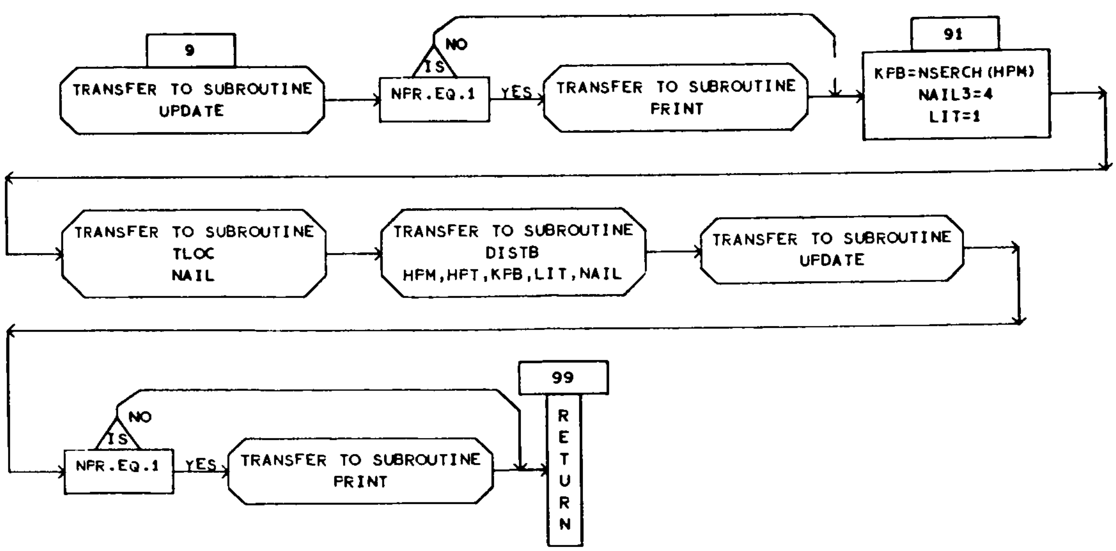


Figure 3-5. Subroutine Flow Charts, PROCES, ROOT, SFORCE, TERMN, and TLOC (Sheet 6 of 8)

TERMN LIST,REF

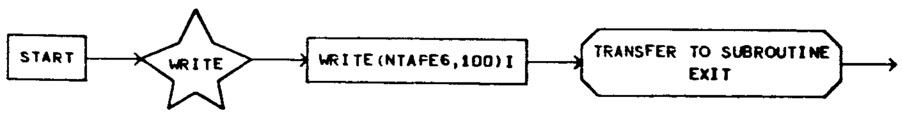


Figure 3-5. Subroutine Flow Charts, PROCES, ROOT, SFORCE, TERMN, and TLOC (Sheet 7 of 8)

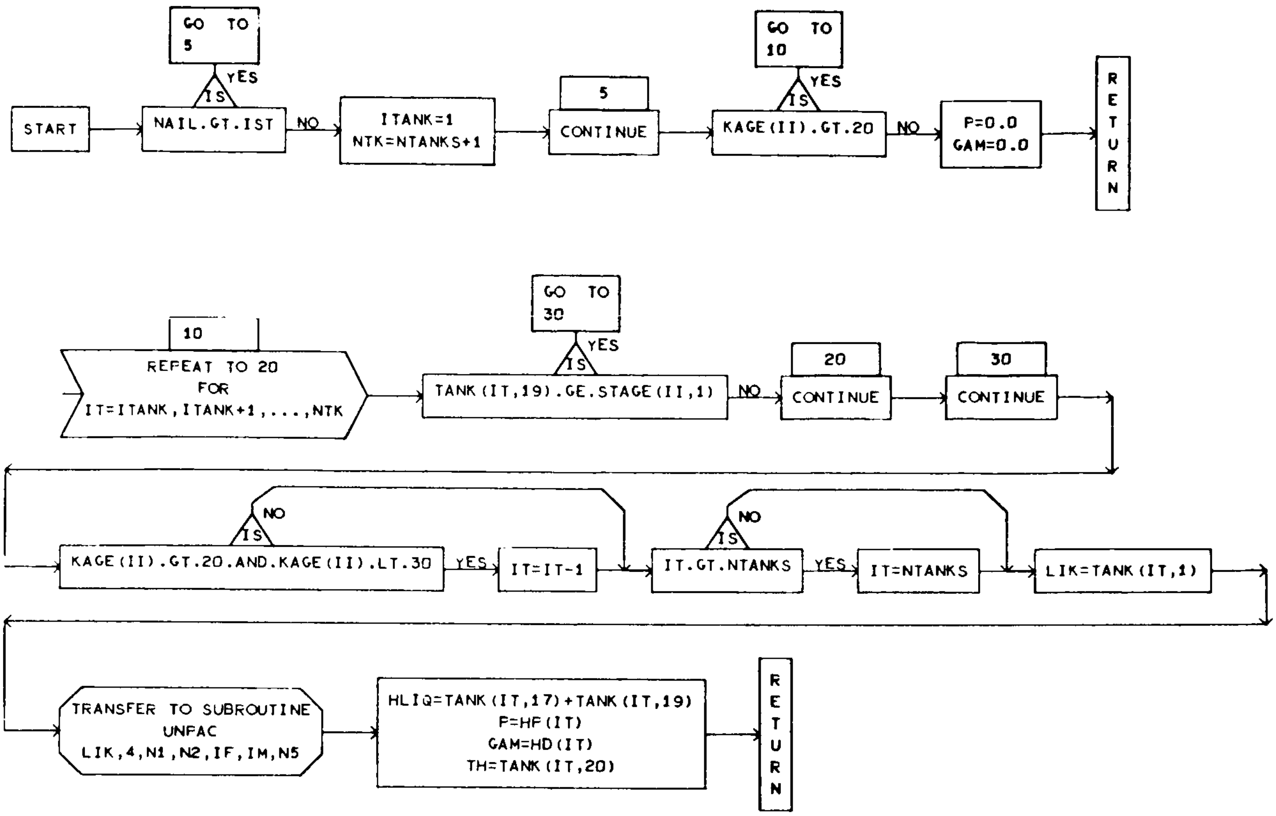


Figure 3-5. Subroutine Flow Charts, PROCES, ROOT, SFORCE, TERMN, and TLOC (Sheet 8 of 8)

D I M E N S I O N E D   V A R I A B L E S

SYMBOL	STORAGES	SYMBOL	STORAGES	SYMBOL	STORAGES	SYMBOL	STORAGES	SYMBOL	STORAGES
NG	5								

Figure 3-6. Subroutine Flow Charts, UNPAC, UPDATE (Sheet 1 of 5)

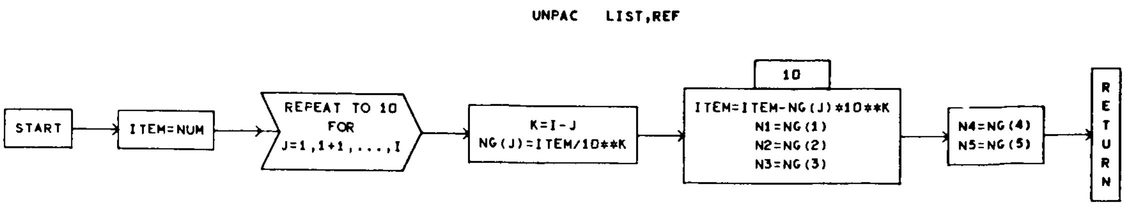


Figure 3-6. Subroutine Flow Charts, UNPAC, UPDATE (Sheet 2 of 5)

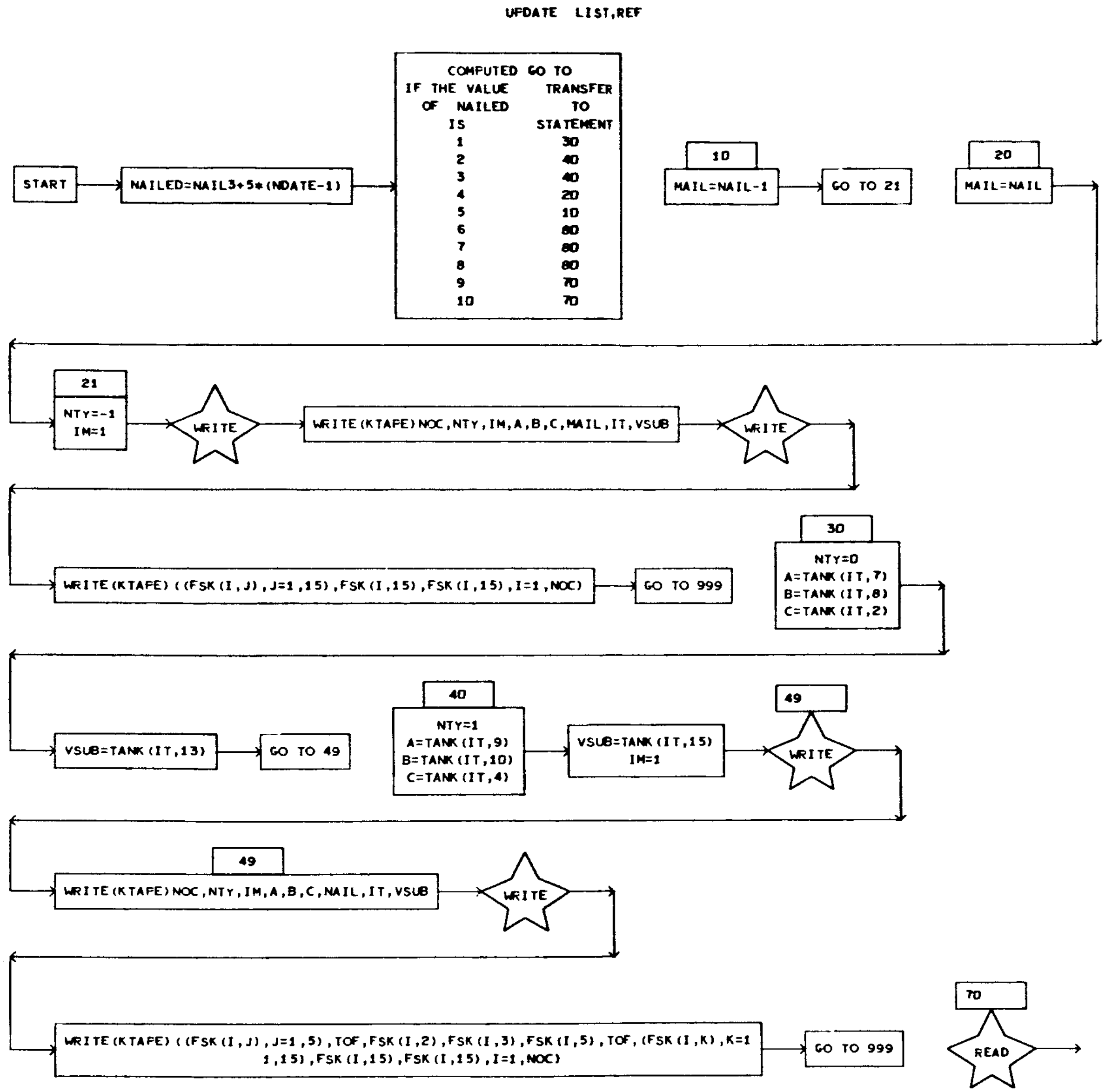


Figure 3-6. Subroutine Flow Charts, UNPAC, UPDATE (Sheet 3 of 5)

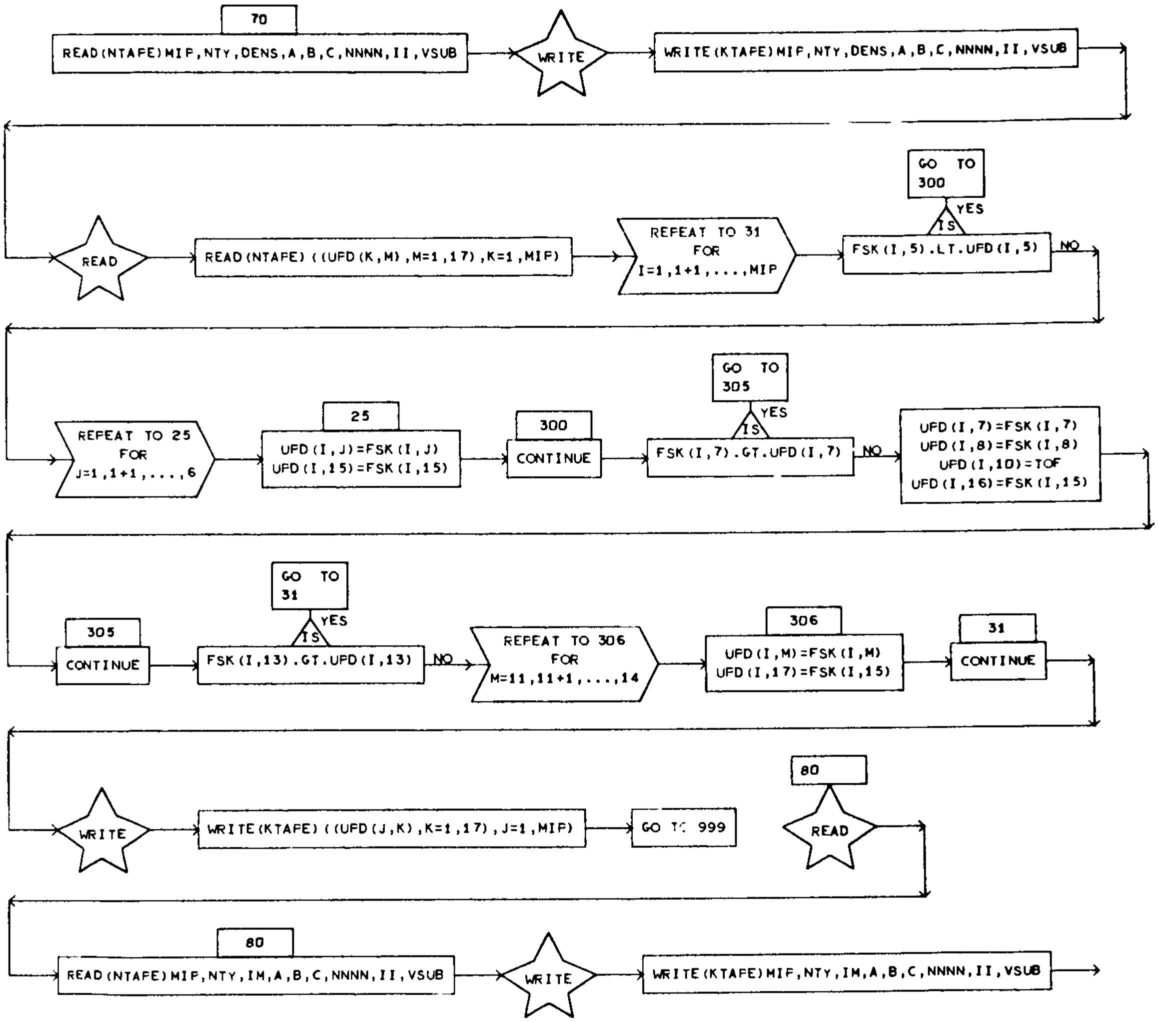


Figure 3-6. Subroutine Flow Charts, UNPAC, UPDATE (Sheet 4 of 5)

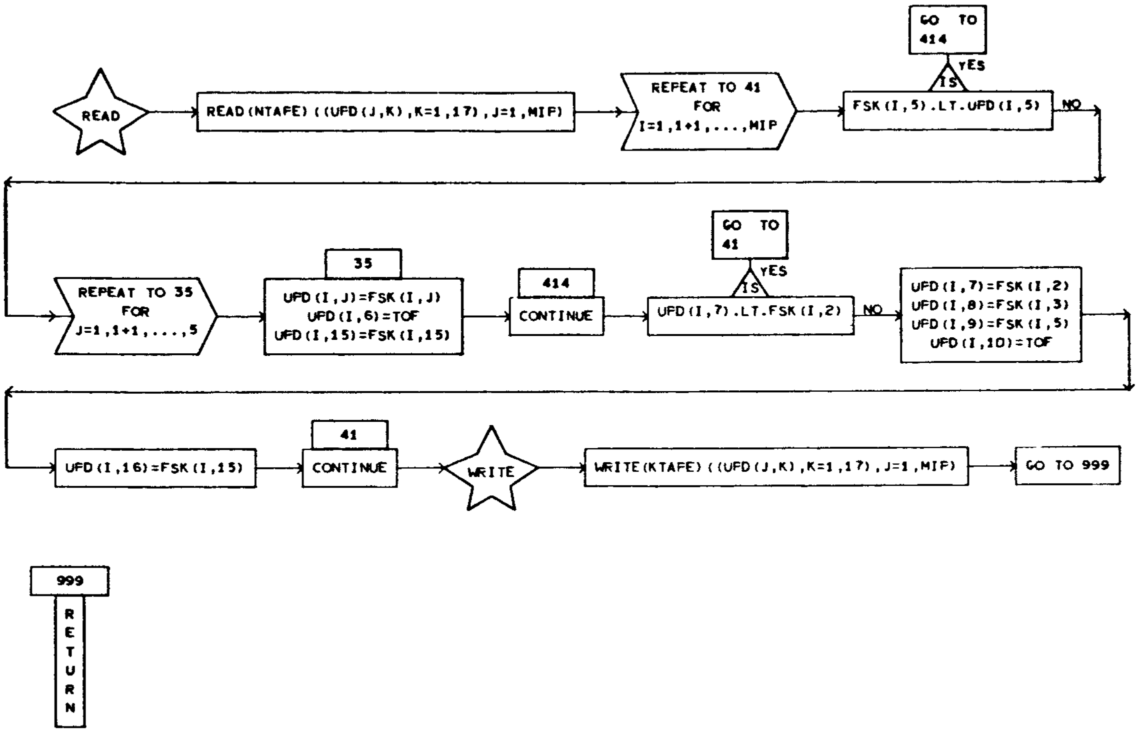


Figure 3-6. Subroutine Flow Charts, UNPAC, UPDATE (Sheet 5 of 5)

DIMENSIONED VARIABLES

SYMBOL	STORAGES	SYMBOL	STORAGES	SYMBOL	STORAGES	SYMBOL	STORAGES	SYMBOL	STORAGES
MINUS	9								

Figure 3-7. Subroutine Flow Charts, VOLUME (Sheet 1 of 3)

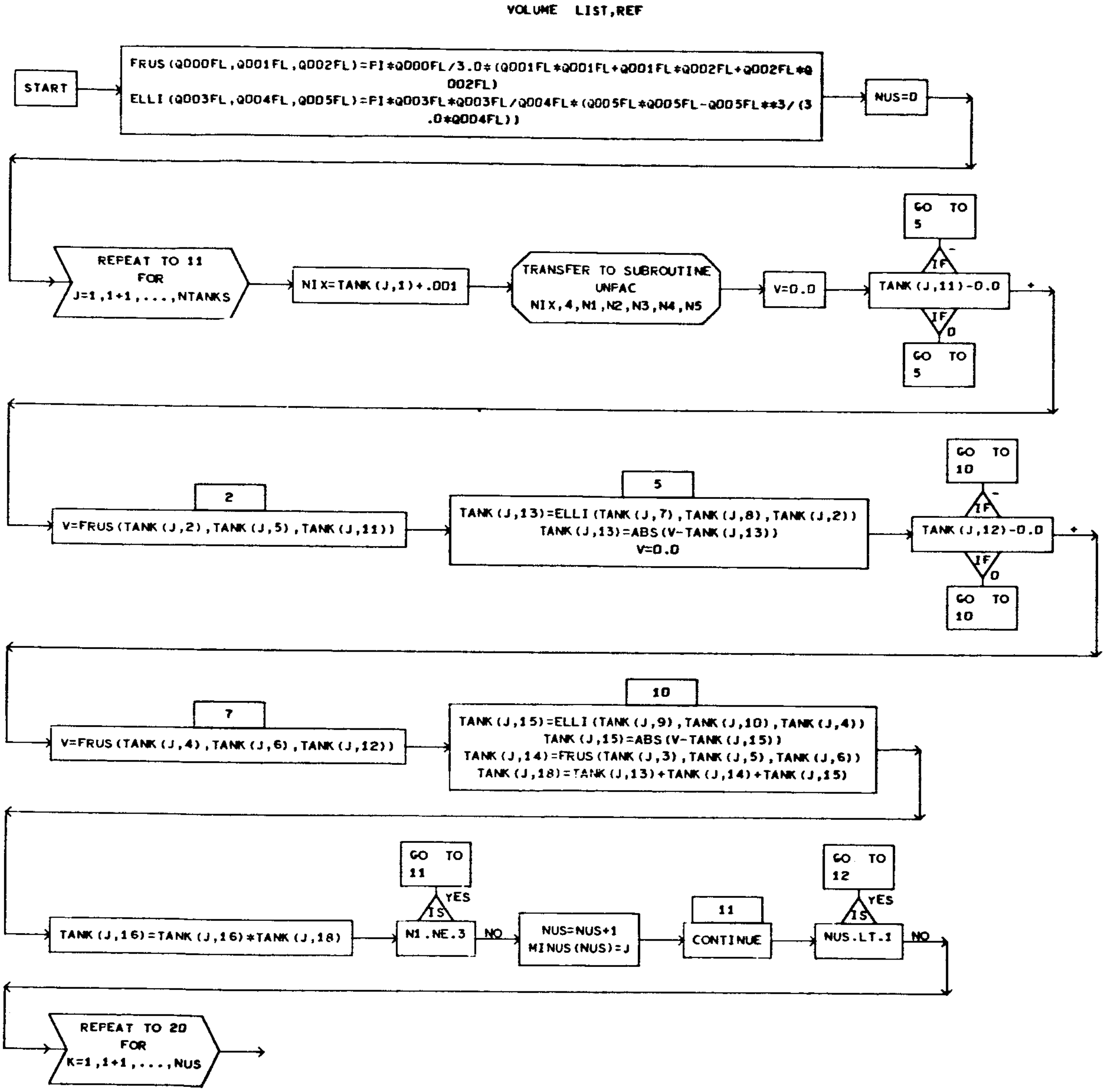


Figure 3-7. Subroutine Flow Charts, VOLUME (Sheet 2 of 3)

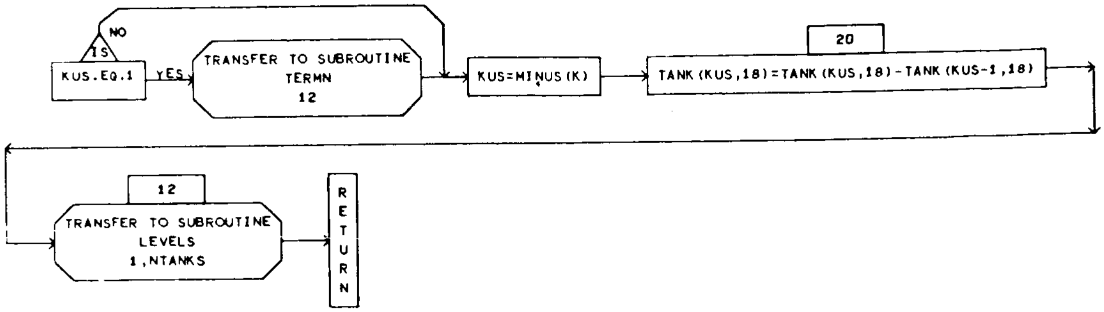


Figure 3-7. Subroutine Flow Charts, VOLUME (Sheet 3 of 3)

g. ROOT - Finds roots of 1 to 4^{th} degree equations.

h. TERMN - Error exit routine.

i. TLOC - Determines specific information about area to be analyzed.

j. UNPAC - Deciphers control words.

k. UPDATE - Writes and edits a summary tape.

l. VOLUME - Finds partial and total volumes of vehicles tanks.

m. GLINT - Generalized linear interpolator.

3.2.1.3 Output Routines

a. ATITLE - Prints basic case information.

b. BTITLE - Prints specific case information.

c. PRINT - Prints specific structural information.

3.2.1.4 Input Routines

PROCES - Reads header cards.

3.2.2 ERROR RETURNS

The STRESS program has two types of error returns which are as described in the following paragraphs.

3.2.2.1 Non-Fatal

Non-fatal errors are those errors which occur upon the initialization of a case. When a non-fatal type of error is encountered, an appropriate message is written off line, the base being processed is skipped, and the program continues with the next case.

3.2.2.2 Fatal

Fatal errors are those which are encountered while a case is being executed. If a fatal error is encountered, the comment ERROR CODE = N will be printed off line and the program will come to a halt. N may take on the following two values:

88 - a nonexistent table has been requested.

3 - the Newton-Raphson's method failed to emerge on a root.

3.2.3 DICTIONARY OF PROGRAM SYMBOLS

3.2.3.1 INPUT

The labeled common named INPUT is used to store information which is read from the LASS input tape.

a. XSTAS (I, 1) = the height from a 0.0 reference point as defined by LASS.

b. XSTAS (I, 2) = the moment at height XSTAS (I, 1).

c. XSTAS (I, 3) = the force at height XSTAS (I, 1).

d. LAST = flag to signify flight status.

  1 = flight (any time point).

  2 = last time point for specific flight.

  3 = last time point for last flight on the tape.

e. TOF = time of flight.

f. AAXIL = axial acceleration.

g. NSTAS = number of stations (index I in the XSTAS array).

h. DUM (1) = LRUN = the run number assigned by the LASS program.

i. DUM (I) (I = 2, 6) = not used.

3.2.3.2 SPEC

The labeled common SPEC contains the vehicle's specifications.

a. STAGE (I, 1) = height above 0.0 reference point of the discontinuity.

b. STAGE (I, 2) = radius at STAGE (I, 1).

c. KAGE (I) = type of discontinuity at STAGE (I, 1). (See input requirements.)

d. TANK (N, 1) = type of tank. (See input requirements.)

e. TANK (N, 2) = the distance from the lowest point on the tank to the highest point of the bottom head.

f. TANK (N, 3) = the distance from the highest point of the bottom head to the lowest point of the top head.

g. TANK (N, 4) = the distance from the lowest point of the top head to the highest point on the tank.

h. TANK (N, 5) = radius of the tank at TANK (N, 2).

i. TANK (N, 6) = radius of the tank at TANK (N, 3) + TANK (N, 2).

j. TANK (N, 7) = semimajor axis of the bottom head.

k. TANK (N, 8) = semiminor axis of the bottom head.

l. TANK (N, 9) = semimajor axis of the top head.

m. TANK (N, 10) = the semiminor axis of the top head.

n. TANK (N, 11) = radius of the tank at its lowest point.

o. TANK (N, 12) = radius of the tank at its highest point.

p. TANK (N, 13) = volume of bottom head.

q. TANK (N, 14) = volume of midsection of tank.

r. TANK (N, 15) = volume of top head.

s. TANK (N, 16) = ullage volume.

t. TANK (N, 17) = height of liquid level in the tank.

u. TANK (N, 18) = total volume of the tank.

v. TANK (N, 19) = not used.

w. TANK (N, 20) = cone angle at the liquid level.

x. FUEL (K, 1) = burn rate of the fuel.

y. FUEL (K, 2) = specific weight of the fuel.

z. FUEL (K, 3) = temperature of fuel.

aa. FUEL (K, 4) = temperature of the gas over the fuel.

ab. FUEL (K, 5) = not used.

3.2.3.3 CONTROL

The labeled common CONTROL contains control flags used in this program.

a. STIME = the starting time of flight to be analyzed.

b. ETIME = the ending time of flight to be analyzed.

c. NPR = the print flag.

d. DT = delta time.

e. NTANKS = number of tanks on the vehicle.

f. NSTAGE = number of discontinuities on the vehicle.

g. IST = discontinuity number where analysis will be started.

h. LST = discontinuity number where analysis will be stopped.

i. NAIL = discontinuity number of the section being analyzed.

j. NAIL1 = not used.

k. NAIL2 = not used.

l. NAIL3 = type of head which is being analyzed.

m. NOC = number of analysis points in section being analyzed.

n. IT = tank number of section being analyzed.

o. IF = fuel number of section being analyzed.

p. IM = dummy metal number.

q. NTAPE = FORTRAN logical tape number 2 or 3.

r. KTAPE = the number that NTAPE is not.

s. NDATE = signal for a one-time point job.

t. KOUNT = run number of LASS flight to be searched for.

u. DH = height increment at which the analysis will be done.

v. IFUEL = number of fuels.

w. IMETAL = not used.

x. KHYDRO = hydrostatic test flag.

y. KBUCKL = not used.

z. KMEMBR = membrane analysis flag.

aa. PSTART = time of flight when printing will begin.

ab. PEND = time of flight when printing will stop.

3.2.3.4 COMPUT

The labeled common COMPUT is used for intermediate storage for a computed structural section.

a. FSK (I, 1) = height.

b. FSK (I, 2) = N_x for $(N_x{}^2 + N_\theta{}^2 - N_xN_\theta)^{\frac{1}{2}}$.

c. FSK (I, 3) = N_θ for $(N_x{}^2 + N_\theta{}^2 - N_xN_\theta)^{\frac{1}{2}}$.

d. FSK (I, 4) = radius (negative radius means the hydrostatic test has been performed).

e. FSK (I, 5) = $(N_x{}^2 + N_\theta{}^2 - N_xN_\theta)^{\frac{1}{2}}$.

f. FSK (I, 6) = time of $(N_x{}^2 + N_\theta{}^2 - N_xN_\theta)^{\frac{1}{2}}$.

g. FSK (I, 7) = N_x for buckling.

h. FSK (I, 8) = N_θ for buckling.

i. FSK (I, 9) = not used.

j. FSK (I, 10) = time for buckling.

k. FSK (I, 11) = N_x for $(N_x + N_\theta)$.

l. FSK (I, 12) = N_θ for $(N_x + N_\theta)$.

m. FSK (I, 13) = $N_x + N_\theta$.

n. FSK (I, 14) = time for $(N_x + N_\theta)$.

o. FSK (I, 15) = temperature.

p. P = pressure over fuel of tank being considered.

q. GAM = specific weight of fuel of tank being considered.

r. TH = cone angle at liquid level.

s. GF = gravitational force.

t. GG = 1.0.

u. HLIQ = liquid level height of tank being considered from 0.0 reference.

v. HP (I) = pressure in tank (I) at time being analyzed.

w. HD (J) = specific weight of fuel in tank (I) at time being analyzed.

x. THT (I) = the total height of tank (I).

3.2.3.5 TSTORE

The labeled common TSTORE is used as a buffer for the updating procedure.

a. UPD (I, 1) = FSK (I, 1).

b. UPD (I, 2) = FSK (I, 2).

c. UPD (I, 3) = FSK (I, 3).

d. UPD (I, 4) = FSK (I, 4).

e. UPD (I, 5) = FSK (I, 5).

f. UPD (I, 6) = FSK (I, 6).

g. UPD (I, 7) = FSK (I, 7).

h. UPD (I, 8) = FSK (I, 8).

i. UPD (I, 9) = FSK (I, 9).

j. UPD (I, 10) = FSK (I, 10).

k. UPD (I, 11) = FSK (I, 11).

l. UPD (I, 12) = FSK (I, 12).

m. UPD (I, 13) = FSK (I, 13).

n. UPD (I, 14) = FSK (I, 14).

o. UPD (I, 15) = temperature at which $\sqrt{N_x^2 + N_\theta^2 - N_x N_\theta}$ occurred.

p. UPD (I, 16) = temperature at which lowest value of N_x occurred.

q. UPD (I, 17) = temperature at which minimum $(N_x + N_\theta)$ occurred.

3.2.3.6 CONST

The common labeled CONST contains constants which are used throughout the program.

a. PI = π.

b. EXTRA = not used.

c. REFF = not used.

d. HGAM = specific weight of fluid used in hydrostatic test.

e. ZFD = force multiplier.

f. ZMD = moment multiplier.

g. HYMX = hydrostatic multiplier.

SECTION 4

CONSTRUCTION SUBPROGRAMS

4.1 MONOCOQUE CYLINDER OR CONE SUBPROGRAM

4.1.1 INTRODUCTION

This subprogram finds the skin thickness required to withstand membrane-type stresses as analyzed by the von Mises-Hencky theory. At the specification of an option the minimum thickness required to resist buckling under axial load will be computed using the method of Lackman and Penzien in Reference 17 of the user's manual.

The minimum thicknesses required to resist these modes of failure are then compared, and the structure then is designed to the governing condition. Details of the adaptations of both these theories used in this program are given in Appendix G of the user's manual.

Since the stress resultants change along the stations for a particular structural section, a continuously varying skin thickness would result. Because a practical structure is made of sheets having a constant thickness, each structural cylinder is divided up into equal length sheets not longer than an input manufacturing maximum sheet length, and each sheet has constant thickness able to withstand the maximum loading in that sheet. Manufacturing minimum gage and yield stress and ultimate stress safety factors are considered in determining skin thicknesses.

4.1.2 FLOW CHART EXPLANATION

4.1.2.1 Inputs

Inputs guiding flow through the flow chart are as follows:

a. NSHEET = the number of sheets this cylinder has been divided into by the LOOP routine. Maximum membrane and buckling loads have been picked out for each sheet by the same routine.

b. NBUCK = signal which indicates whether buckling analysis is to be performed.

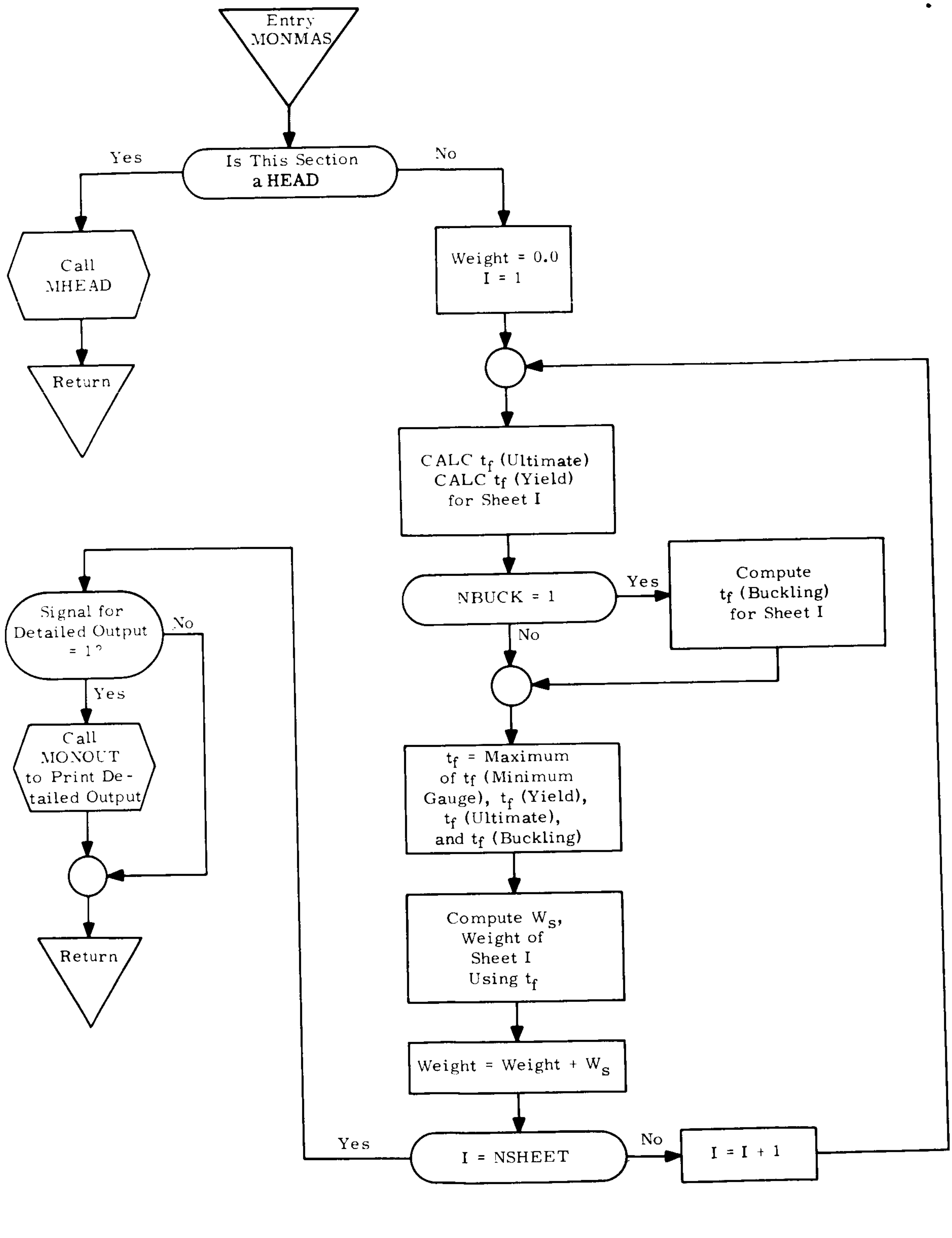


Figure 4-1. MONMAS

c. NC (152) = signal indicating whether detailed intermediate output should be printed out.

4.1.2.2 Variables

Variable names used in the flow chart are as follows:

a. WEIGHT = total weight of cylindrical structure.

b. W_s = weight of sheet under consideration.

c. I = index used for sheet number in loop to compute weight of each sheet.

d. t_f(ultimate) = skin thickness when analyzing membrane solution for ultimate stress failure.

e. t_f(yield) = skin thickness when analyzing membrane solution for yield stress failure.

f. t_f(buckling) = skin thickness required to resist buckling failure. Set to 0.0 if NBUCK = 0.

g. t_f(maximum) = skin thickness required to resist governing mode of failure.

4.1.2.3 Subroutines

The subroutines used are:

a. MHEAD - handles analysis of monocoque heads construction. Has own program document.

b. MONOUT - prints out intermediate output for each sheet which has been stored in the THICK array in common.

4.1.3 SPECIAL ATTENTION ITEMS

The program has no iterations and no error returns.

4.2 MONOCOQUE HEADS SUBPROGRAM

4.2.1 INTRODUCTION

This subprogram finds the minimum weight monocoque shell design for an ellipsoidal head under a given loading which may include external pressure. The subprogram is called when the head is divided up into practical sheet lengths and maximum loads for each sheet have been picked out. An exception is if the monocoque head is called from the waffle program as a substitute for the waffle heads construction, in which case sheet divisions are dummied for one sheet, and maximum loads are picked out.

The first step is to find the minimum skin thickness for each sheet needed to withstand the maximum membrane load in the sheet. The von Mises-Hencky theory is used here.

The minimum skin thickness needed to resist buckling is then found for each sheet. This is done by converting the ellipsoidal head to an equivalent sphere and using the classical von Karmen-Tsien formula. The buckling analysis is optional, and is performed only when an input signal asks for it.

The maximum skin thickness of the two is then picked to design the final sheet to withstand the governing condition. If no buckling analysis is specified, the membrane load face thickness only is used. The manufacturing minimum gage of the material being used is considered here.

4.2.2 FLOW CHART EXPLANATION

The following inputs govern flow through this routine:

a. WEIGHT = total weight of this head.

b. I = index to keep count of sheets.

c. t_f(ultimate) = skin thickness required to withstand membrane load with respect to failure by ultimate stress and its safety factor.

d. t_f(yield) = skin thickness required to withstand membrane load with respect to failure by yield stress and its safety factor.

e. A = semimajor axis of ellipsoidal head.

f. B = semiminor axis of ellipsoidal head.

g. NBUCK = signal for buckling analysis.

h. t_f(buckling) = skin thickness required to resist buckling. Set to 0.0 if NBUCK = 0.

i. t_f(minimum gage) = manufacturing minimum thickness for material being used.

j. t_f = final sheet thickness for governing condition.

k. W_s = weight of sheet I.

l. NSHEET = total number of sheets for this head.

4.2.3 SPECIAL ATTENTION ITEMS

The program has no iterations, but does have the following error return. Current design capability for construction programs and current Saturn V configuration dictate that all elliptical heads must be tangent to the cylinder to which they are attached

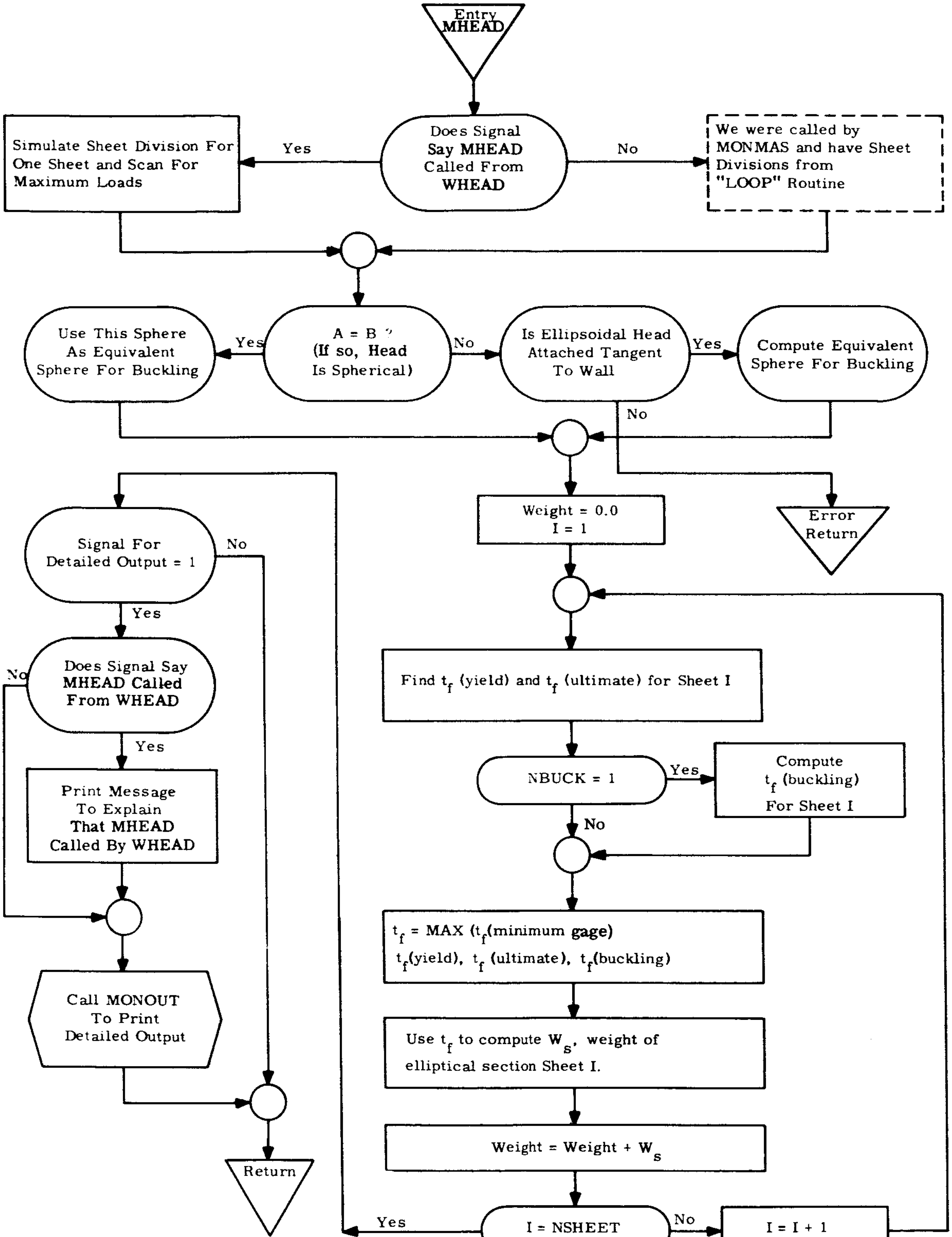


Figure 4-2. MHEAD

(spherical heads need not be tangent to their cylinder). A test is made to assure that all ellipsoidal heads are tangent to their supporting cylinder, and a fatal error with exit called results if the test is violated. This, however, should never happen if input to the stress program is correct and there is no computer malfunction.

4.3 HONEYCOMB CYLINDER OR CONE SUBPROGRAM

4.3.1 INTRODUCTION

The function of this subprogram is to find the minimum weight honeycomb sandwich cylinder to withstand the given loading condition. Two modes of failure are considered: strength failure as analyzed by the von Mises-Hencky theory, and buckling failure which includes general instability and various modes of local instability.

The program uses the following procedure to find minimum weight structures. First, minimum face thicknesses required to resist the strength (membrane) load are computed using the von Mises-Hencky theory. Then, the minimum weight face-core thickness combination able to resist the axial load is formed by the theory described in Appendix H of the user's manual. In finding the minimum weight configuration, a series or range of core material shear moduli are considered. The material of least density (and therefore least core shear modulus) is considered first, and the optimum face/core combination is found for it. This design is then checked against criteria for failure via face wrinkling, shear instability, or monocell buckling, or for violation of maximum core thickness. If the design violates any of these modes of local failure, it is rejected. The procedure is repeated for the whole range of values of core shear modulus specified, and the minimum weight design is chosen from the designs which resisted all modes of failure.

The strength face thickness is then compared to the buckling face thickness. If the strength face thickness is greater than the buckling face thickness, the strength face thickness is used, and the core thickness for buckling is correspondingly reduced.

Because stress resultants change from station to station, a continually varying design would result. Since practical structures are designed in sheets of constant thickness, each cylinder is divided into equal length sheets not longer than an input manufacturer's maximum sheet length, and each sheet is designed to the most severe loading in its sheet length.

A structural section is simpler to manufacture if sheets to be joined have equal core thickness. A final adjustment in design is therefore made. The final core thickness of every sheet in the structure is increased to the maximum of any sheet in the structure, and face thicknesses of buckling governed sheets with increased cores are then decreased to optimum thickness.

An option is available with the program to set core thickness to a fixed input value. The face thickness for each sheet is then designed to the minimum that will resist all forms of failure when stabilized by the given core. This is done for all specified values of core shear modulus, and the minimum weight configuration is picked out from these.

4.3.2 FLOW CHART EXPLANATION

4.3.2.1 Subroutine HONMAS

Inputs guiding the flow through the flow chart are as follows:

a. NSHEET = the number of sheets that make up this cylinder. Maximum membrane and buckling loads have been found for each sheet.

b. L_{eq}/R_{eq} = ratio of equivalent length to equivalent radius. Used to bypass buckling solution for extremely short sections.

Variables used in the flow chart are as follows:

a. t_f(ult) = face thickness for membrane load designing to ultimate stress and safety factor.

b. t_f(y) = face thickness for membrane load designing to yield stress and safety factor.

c. L_{eq} = equivalent length (used in transforming conical sections to cylinders).

d. R_{eq} = equivalent radius (used in transforming conical sections to cylinders).

e. t_f(strength) = governing membrane face thickness [maximum of t_f(ult) and t_f(y)].

f. t_f(buckle) = optimum face thickness when only buckling is considered.

g. t_c(buckle) = optimum core thickness when buckling only is considered.

h. t_f(semifinal) = governing face thickness for a sheet equal to maximum of t_f(strength) and t_f(buckle) minimum manufacturer's gage also is considered.

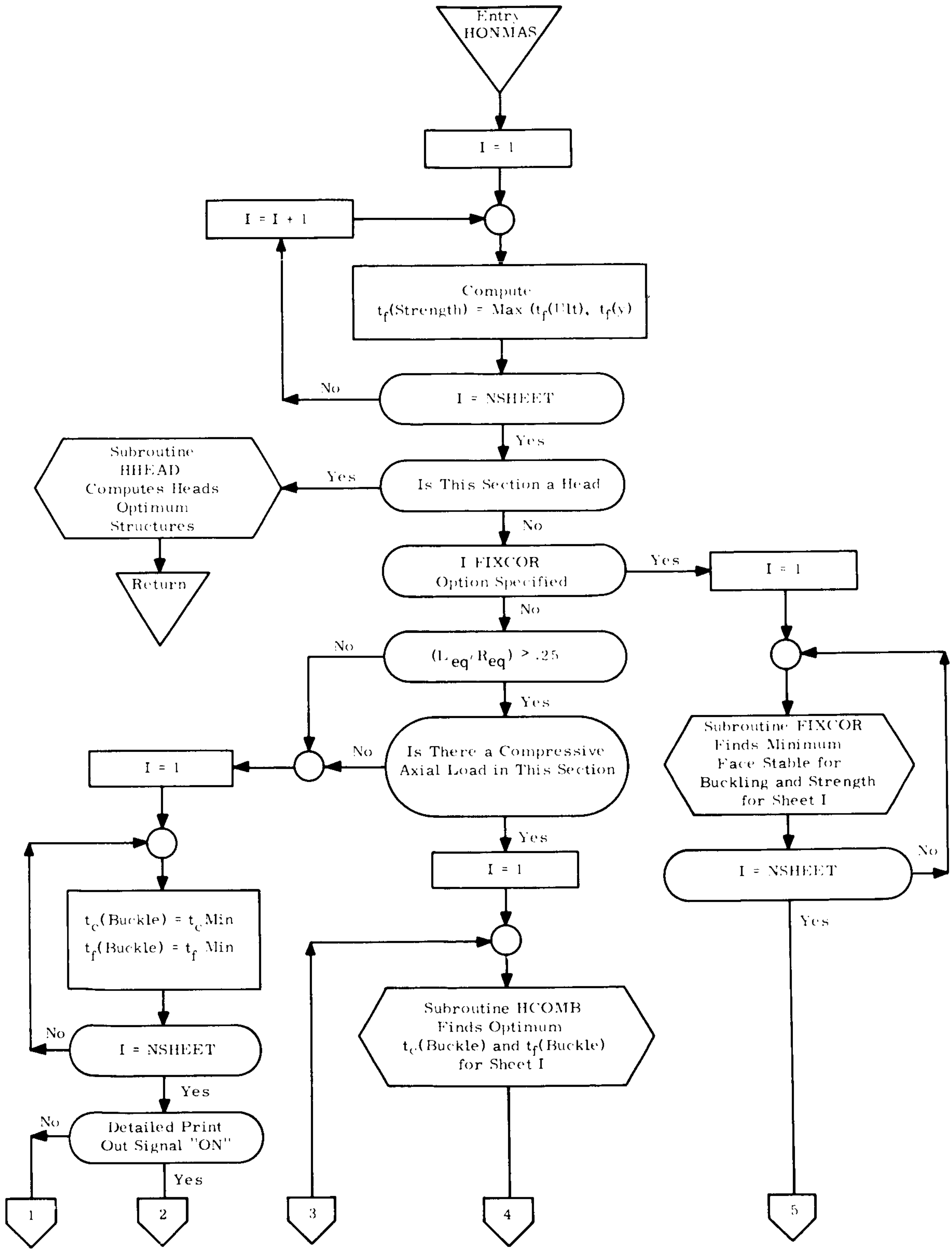


Figure 4-3. HONMAS (Sheet 1 of 2)

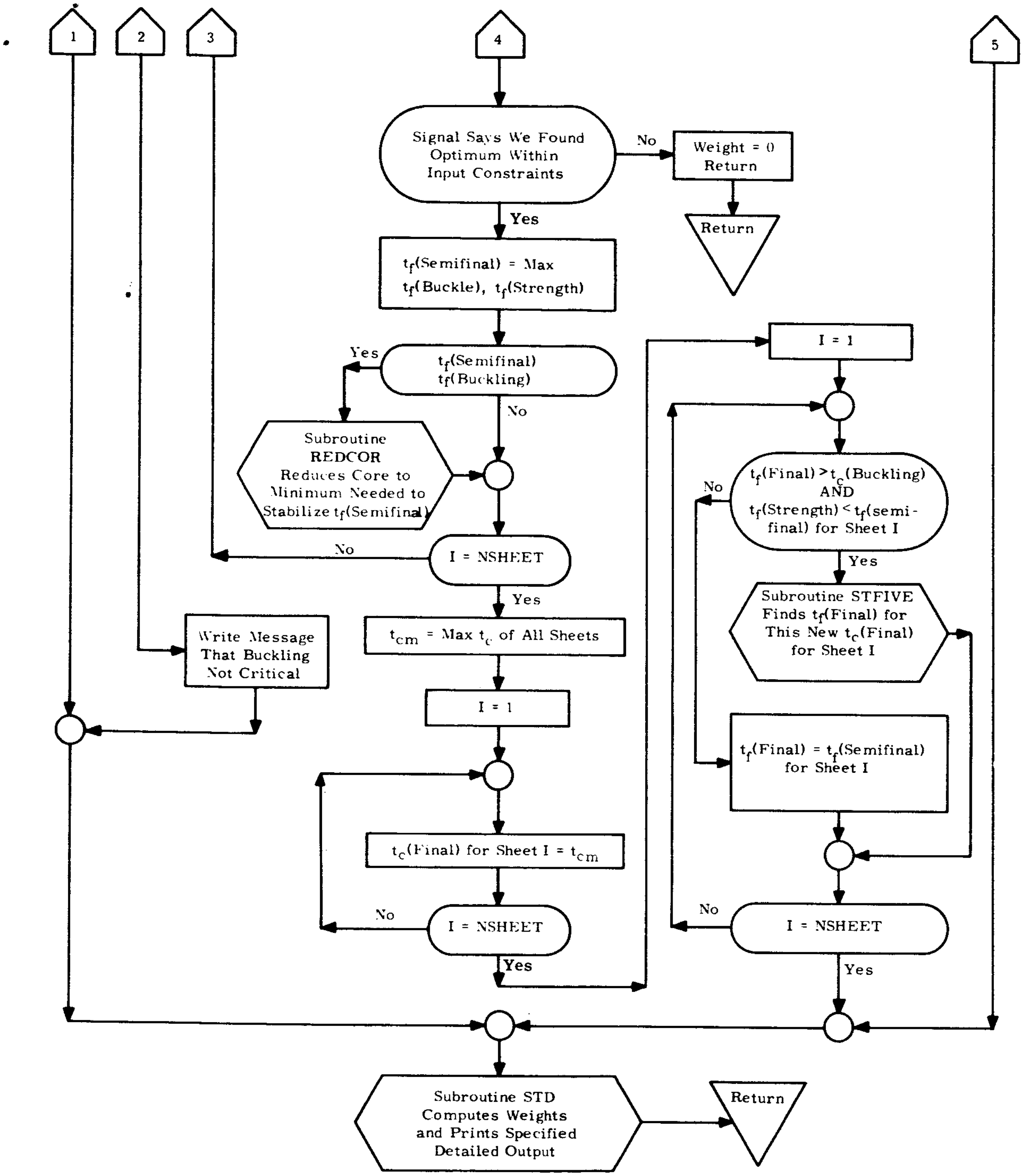


Figure 4-3. HONMAS (Sheet 2 of 2)

i. t_c = semifinal core thickness (reduced from t_c(buckle) if t_f(semifinal) was increased over t_f(buckle).

j. t_cM = maximum t_c over all sheets.

k. t_c(final) = uniform core thickness for all sheets (equal to t_cM).

l. t_f(final) = final face thickness when uniform thickness core has been applied to all sheets. Decreased from t_f(semifinal) for buckling-governed sheets the optimum core thickness of which was increased to t_c(final) for uniform core requirement.

m. $t_c$min = minimum allowable core thickness.

n. $t_f$min = minimum allowable face thickness.

4.3.2.2 Subroutine HCOMB

Flow control symbol and variable explanations are as follows:

a. GLT (face wrinkling) = minimum core shear modulus required to keep the faces from wrinkling.

b. GLT (shear instability) = minimum core shear modulus required to resist shear instability.

c. GLT = core shear modulus under consideration for present case.

d. d_{cor} = maximum allowable core cell diameter to resist monocell buckling.

e. d_{cor} min = manufacturing minimum core cell diameter for the value of GLT under consideration.

f. T_{cor} = core thickness (optimum) for the GLT under consideration.

g. T_c max = maximum allowable core thickness.

h. SIGNAL = switch set to 0 if optimization cannot be performed with the given inputs. Set to 1 if solution has been found.

4.3.2.3 Subroutine TONINE

Flow control symbol explanations are as follows:

a. σ = face stress input into STEPTO to find core thickness needed to stabilize this stress level.

b. σ_y = yield stress.

c. t_c = core thickness.

d. w_y = weight of configuration where faces operate at yield stress.

e. K_1 = parameter used in determining optimum face thickness/core thickness combination.

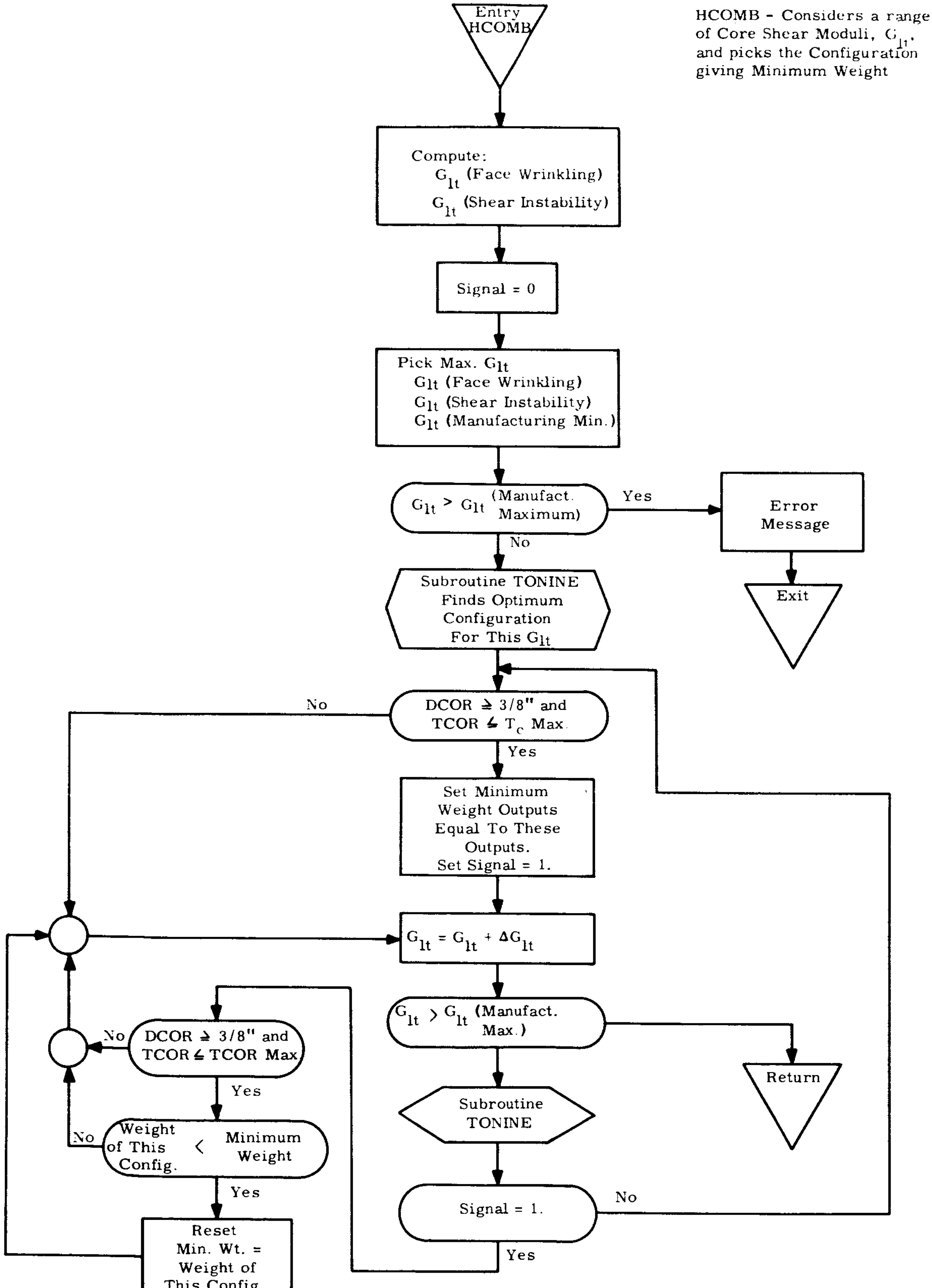
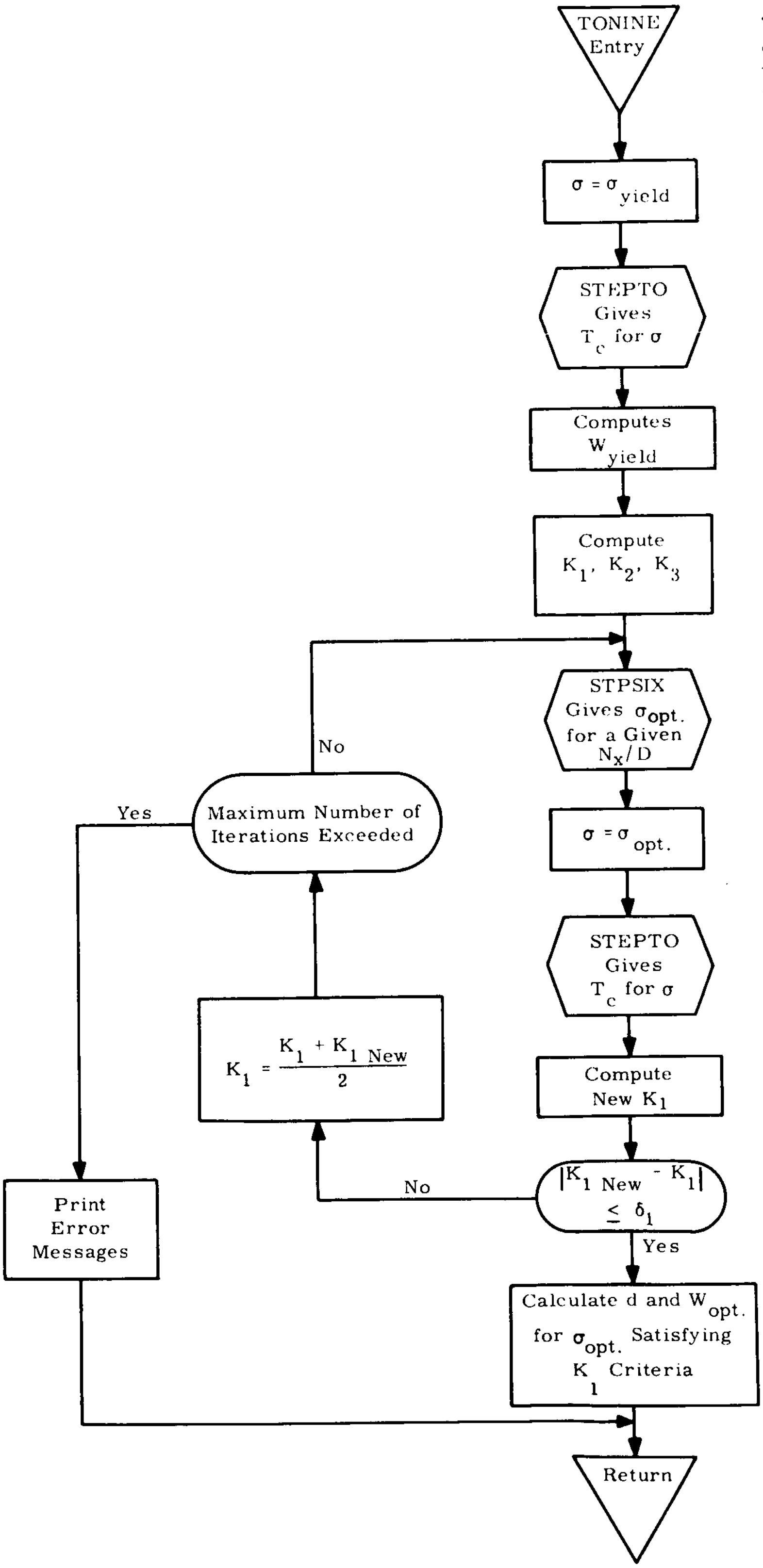


Figure 4-4. HCOMB



TONINE - finds optimum combination of core thickness and face thickness for a given core modulus

Figure 4-5. TONINE

f. K_2 = ratio of core density to face density.

g. σ_{opt} = optimum face stress level for a given structural index (N_x/D).

h. N_x = compressive axial load.

i. D = equivalent diameter (used in transforming cones to equivalent cylinders).

j. d = minimum core cell diameter for this configuration.

k. W_{opt} = weight of optimum configuration for this core shear modulus.

4.3.2.4 <u>Subroutine STEPTO</u>

Flow chart symbol means are as follows:

a. σ = input stress for which to find core thickness needed.

b. T_c initial = value at which to start iterating for T_c.

c. T_c = core thickness.

d. t_f = face thickness for this stress level.

e. u = shear rigidity of panel.

f. D_f = flexural rigidity of panel.

g. J = rigidity parameter.

h. Z = geometry parameter.

i. K_x = buckling coefficient, axial compression.

j. η = plasticity reduction factor for general instability.

k. σ_{new} = stress level that core thickness is able to support (if too far from given stress level, adjust T_c).

l. ΔT_c = amount T_c is to be adjusted to make σ_{new} closer to σ.

m. δ_2 = tolerance on σ in iteration.

4.3.2.5 <u>Subroutine STPSIX</u>

The flow chart symbol definitions are as follows:

a. σ_{yield} = stress of material.

b. σ_{opt} = optimum stress level.

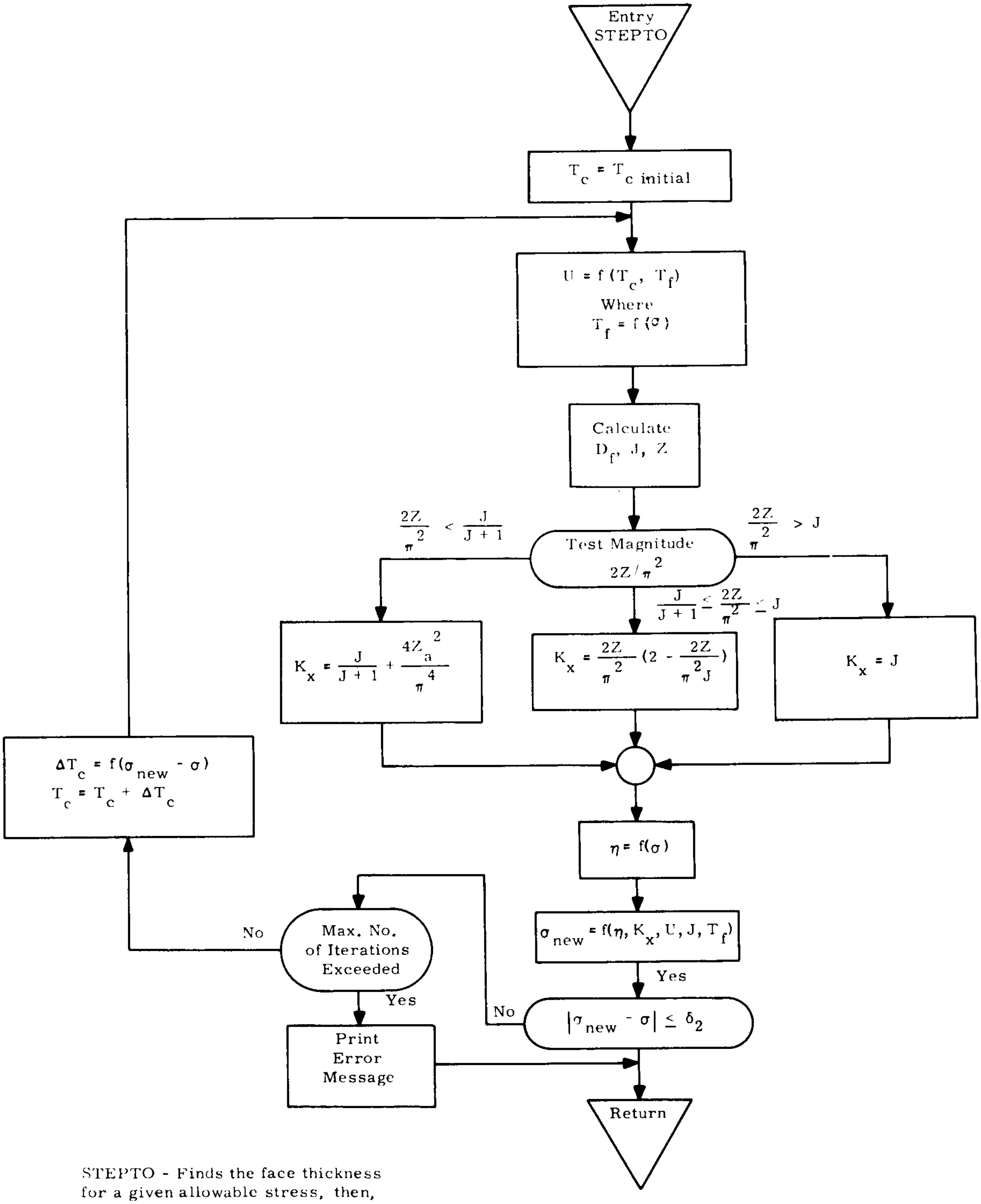
c. N_x/D (input) = input structural index we are trying to hit with the iteration.

d. N_x/D (trial) = structural index we have found as a function of σ_{opt}. This is to be made equal to N_x/D (input).

e. δ_3 = tolerance on N_x/D in iteration.

f. σ_{ult} = ultimate stress of material.

g. S.F.$_{ult}$ = safety factor when designing to σ_{ult}.



STEPTO - Finds the face thickness for a given allowable stress, then, finds the core thickness needed by these faces for the given shear modulus.

Figure 4-6. STEPTO

STPSIX - Finds optimum working stress for a given axial load, Nx, and equivalent cylinder diameter, D.

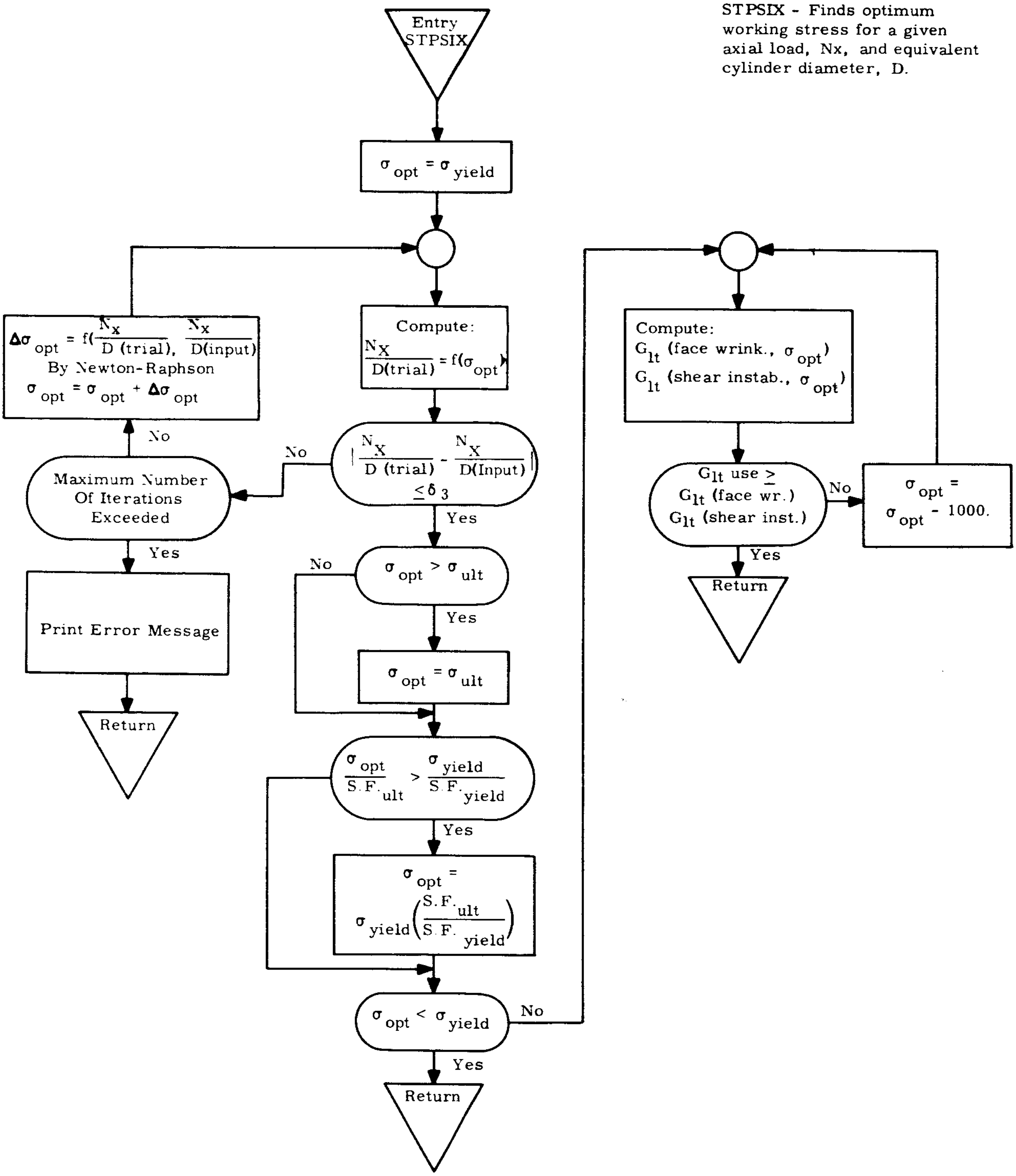


Figure 4-7. STPSIX

h. $S.F._{yield}$ = safety factor when designing to σ_{yield}.

i. G_{lt} (face wrinkling, σ_{opt}) = minimum core shear modulus that will resist face wrinkling for faces operating at stress of σ_{opt}.

j. G_{lt} (shear instability, σ_{opt}) = minimum core shear modulus that will resist shear instability for faces operating at stress level of σ_{opt}.

k. G_{lt} use = core shear modulus presently under consideration. If not sufficient to resist shear instability or face wrinkling, program reduces σ_{opt}.

l. $\Delta\sigma_{opt}$ = increment to add to σ_{opt} to get N_x/D (trial) closer to N_x/D (input). Computed by Newton's method.

4.3.2.6 Subroutine REDCOR

The explanation of flow chart symbols is as follows:

a. σ = stress at which faces operate.

b. T_f = face thickness.

c. T_c = core thickness.

4.3.2.7 Subroutine FIXCOR

Flow chart symbol definitions are as follows:

a. SIGNAL = switch set to zero if no solution is possible. Set to 1.0 if solution is found.

b. t_c given = input core thickness.

c. t_c = core thickness.

d. G_{lt} = core shear modulus under consideration.

e. G_{lt} min = input minimum value of core shear modulus.

f. t_f(buckle) = face thickness needed with this given core to resist buckling.

g. W_{opt} = weight of configuration under consideration.

h. W_{min} = minimum weight of all configurations considered so far.

i. ΔG_{lt} = increments at which to consider values of core shear modulus.

j. G_{lt} max = input maximum value of G_{lt} to consider.

4.3.2.8 Subroutine STFIVE

Definitions of symbols used in flow charts are as follows:

a. T_f(yield stress) = thickness of face when operating at yield stress.

b. T_f = face thickness.

c. T_c = core thickness (given input value).

REDCOR - Reduces Core Thickness For Faces Not Governed By Buckling

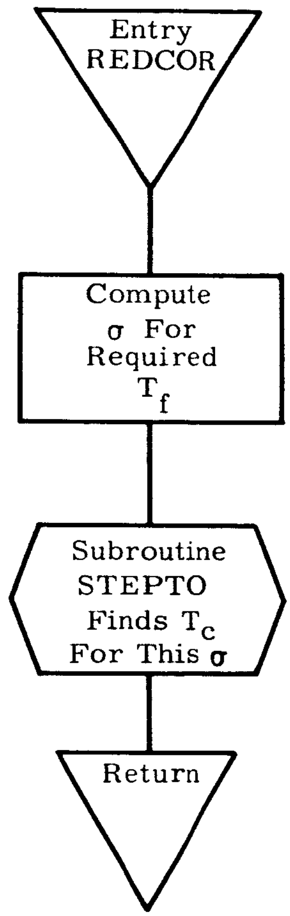


Figure 4-8. REDCOR

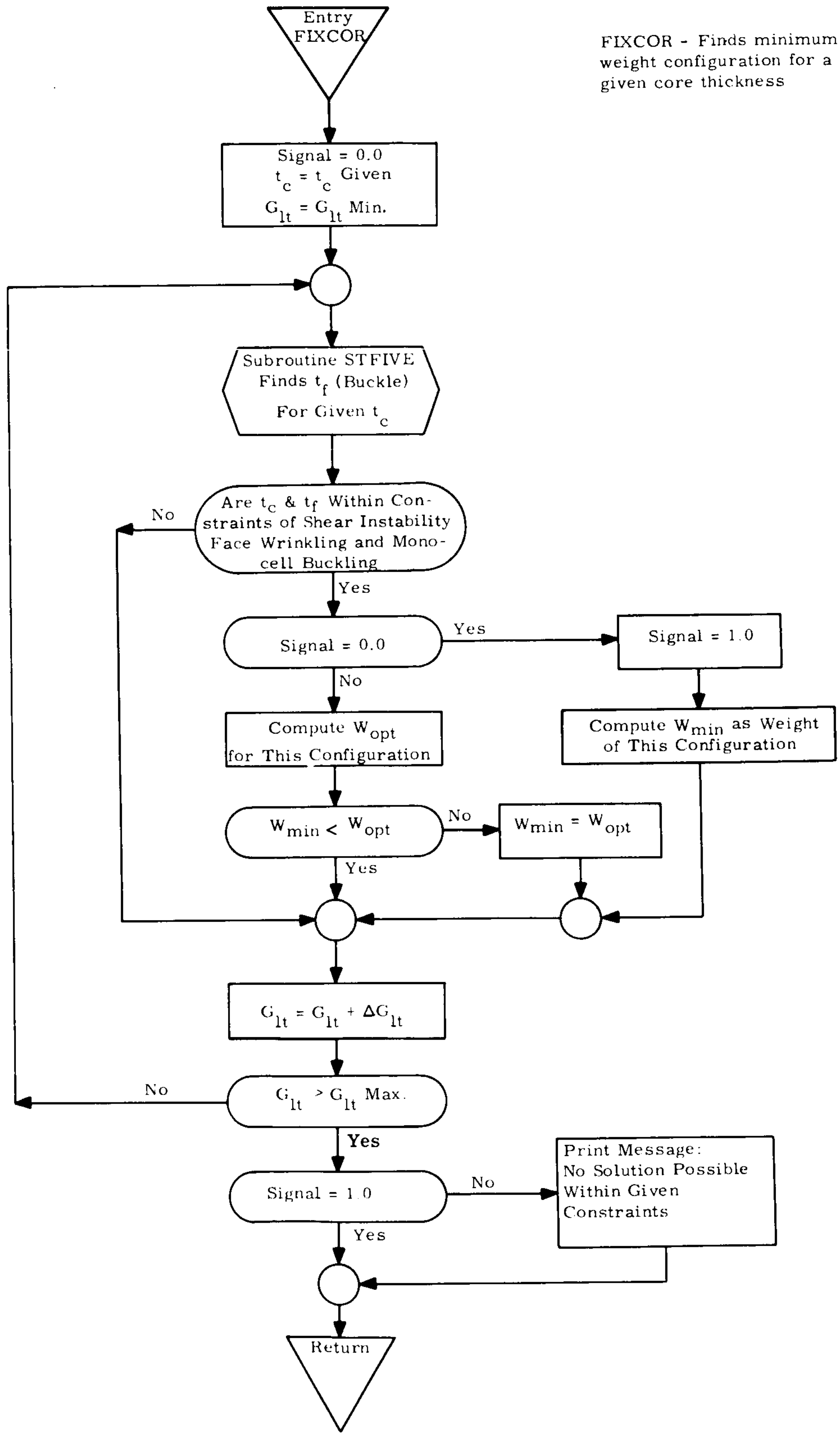


Figure 4-9. FIXCOR

STFIVE - Find the face thickness for a given allowance stress that can be supported by the given core.

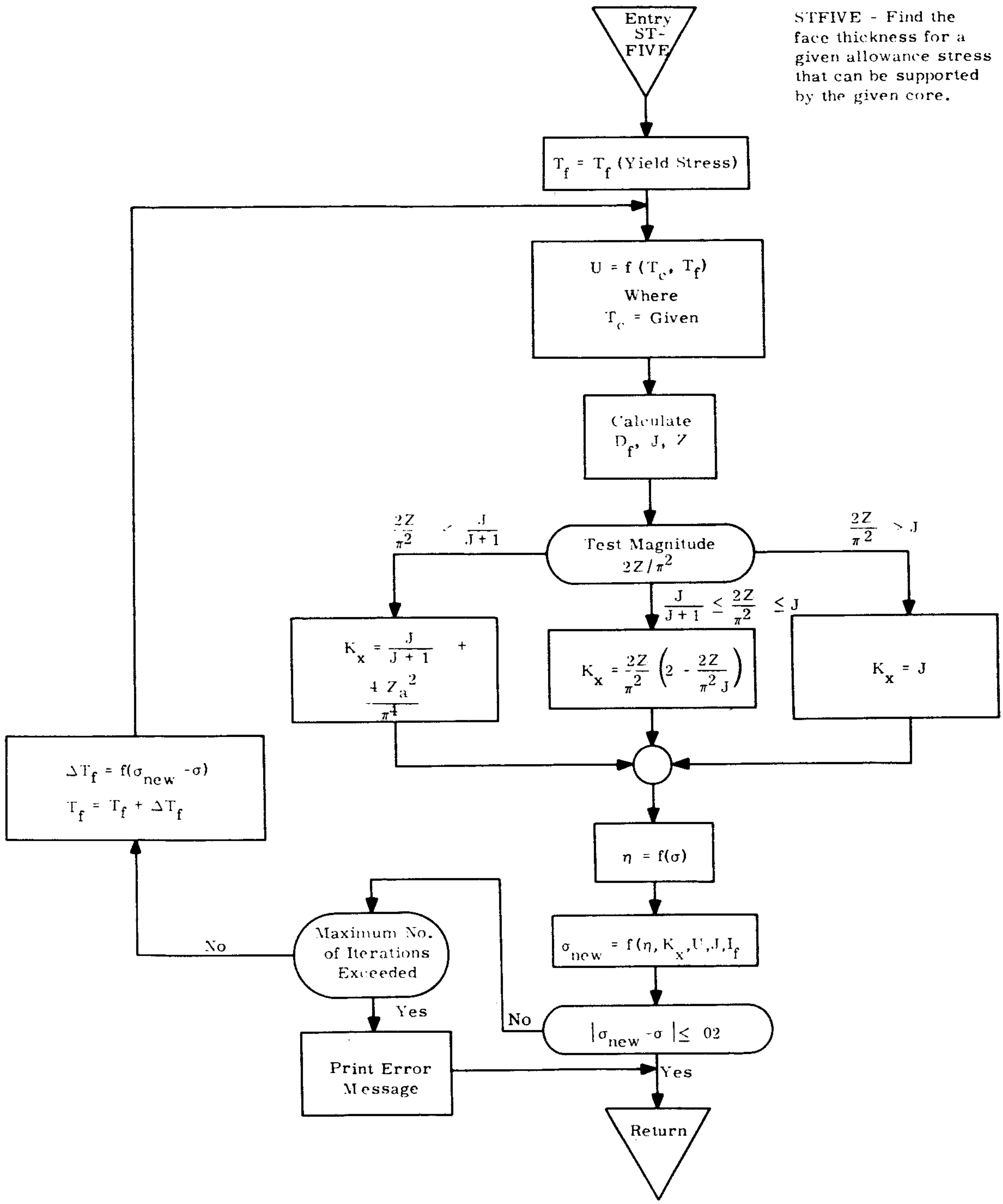


Figure 4-10. STFIVE

d. U = shear rigidity of panel.

e. D_f = flexural rigidity of panel.

f. J = rigidity parameter.

g. Z = geometry parameter.

h. K_x = buckling coefficient, axial compression.

i. η = plasticity reduction factor for general instability.

j. σ_{new} = face stress level that this combination of core and face will allow.

k. σ = actual stress of face with thickness T_f, if too far from σ_{new} we have found, adjust T_f.

l. δ_2 = tolerance on σ in iteration.

m. ΔT_f = amount by which T_f is to be adjusted to make σ_{new} and σ closer to each other.

4.3.3 SPECIAL ATTENTION ITEMS

The iteration for K_1 in subroutine TONINE and the iteration for σ_{opt} in STPSIX have both proven very stable procedures in running of this program. Maximum iteration limit for these iterations has usually been set at 10. Both iterations have error returns to indicate non-convergence.

The iterations for T_c in STEPTO and T_f in STFIVE are not as sophisticated and somewhat unstable for extremely low compressive loads. A maximum iteration limit of 50 iterations has been used. No trouble has been encountered where axial compression is substantial, but the iteration occasionally has broken down for extremely low compressive loads (less than about 250 lbs/inch). This, however, is not a real limitation of the program because honeycomb sandwich structures are useful mainly to resist buckling, and monocoque structures are more efficient where buckling is not critical. Appropriate error messages are printed out if these iterations break down, and zero weight is returned.

Another error return is provided for cases where no core shear modulus specified is great enough to resist shear instability or face wrinkling. This return is not likely to occur in the practical range of G_{lt} usually considered (above 15,000 psi).

4.4 HONEYCOMB HEADS SUBPROGRAM

4.4.1 INTRODUCTION

This subprogram finds the minimum weight configuration of a honeycomb sandwich elliptical head able to withstand a given loading condition. Both strength (membrane load) failure and buckling failure are considered, as well as several forms of local instability. Manufacturing limitations for minimum material thicknesses, minimum core material cell diameters, and core shear moduli are considered.

The following method is used. The minimum face thicknesses to resist the membrane load are calculated first using the von Mises-Hencky theory. Then the minimum weight core thickness/face thickness combination is found for the given axial load. The face/core combination is adjusted off from the apparent optimum if needed to avoid falure by local instability or violation of maximum or minimum core thickness. Detailed theory for buckling is given in Appendix P.

The strength criterion face thickness is compared to the buckling face thickness. If the strength face thickness is the greater of the two, it becomes the face thickness of the configuration and the buckling core is correspondingly reduced.

A structural section is made of sheets having a constant thickness, hence the structure is divided into equal length sheets (subject to an input maximum sheet length limit), and each sheet is designed to the most severe loading in its sheet length.

A structure is simpler to manufacture if sheets to be joined have equal core thickness. A final adjustment is therefore made to the design. Each sheet has its core thickness increased to the maximum for the whole section, and face thicknesses of buckling-governed sheets are reduced accordingly.

In designing each sheet a range of core shear moduli is considered, and the core modulus giving least weight is picked for the final design.

An option is available to input the core thickness to use. The minimum face thickness able to withstand the given load with the input core is then computed for each sheet for a range of core shear moduli, and the minimum weight configuration selected.

4.4.2 FLOW CHART EXPLANATION

4.4.2.1 Subprogram HHEAD

The following symbols are used:

a. A = semimajor axis of ellipsoidal head.

b. B = semiminor axis of ellipsoidal head.

c. C = height of head.

d. t_f(str) = face thickness needed according to von Mises-Hencky membrane analysis.

e. t_f(min) = manufacturing minimum for face.

f. t_c(min) = manufacturing minimum for core.

g. t_f(b) = optimum face thickness for buckling considerations.

h. t_c(b) = optimum core thickness for buckling considerations.

i. NSHEET = number of sheets of metal of which the elliptical head is to be constructed.

j. t_f(sf) = maximum of t_f(str) and t_f(buck).

k. t_c(sf) = core thickness needed for t_f(sf).

l. t_c(max) = greatest t_c(sf) of all sheets, all t_c(f) are set to this.

m. t_c(f) = final uniform core thickness.

n. t_f(f) = final face thickness needed by uniform core.

o. W_{opt} = weight per square foot of an optimum configuration for a particular GLT (core shear modulus).

p. W_{min} = minimum weight for a sheet picked from several GLT.

q. I = sheet index used in loop for the total of NSHEET sheets.

r. NSHEET = total number of sheets in head.

s. N_x = axial load.

t. GLT = core shear modulus under consideration.

u. GLT(max) = maximum allowable core shear modulus.

v. ΔGLT = increments in which to consider values of core shear modulus.

w. t_c(given) = core thickness when input for fixed core thickness option.

4.4.2.2 Subroutine OPTSTR

The following symbols are used:

a. K_1 = ratio of overall thickness to core thickness.

b. ITERAK = iteration counter.

c. σ_y = yield stress.

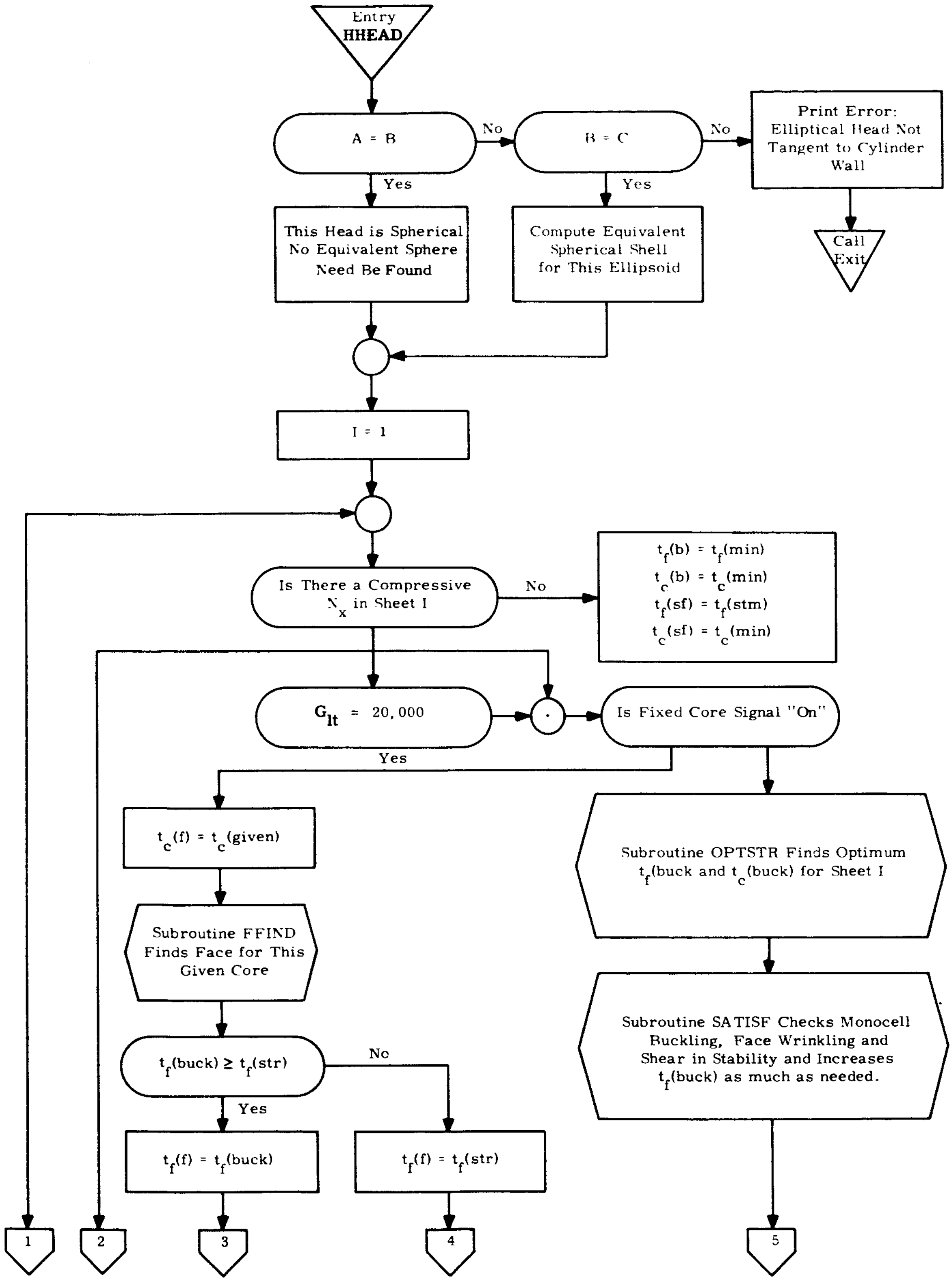


Figure 4-11. HHEAD (Sheet 1 of 2)

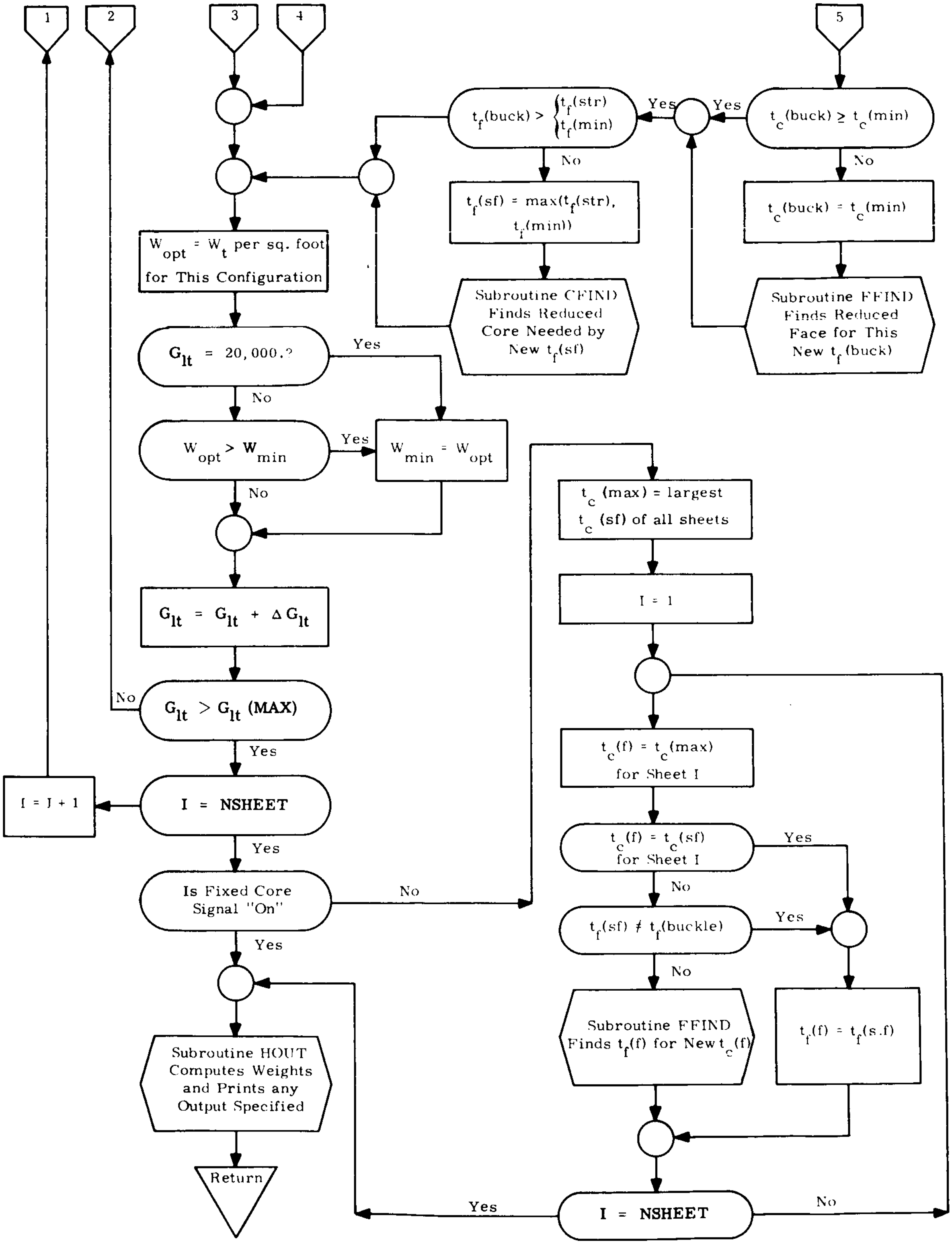
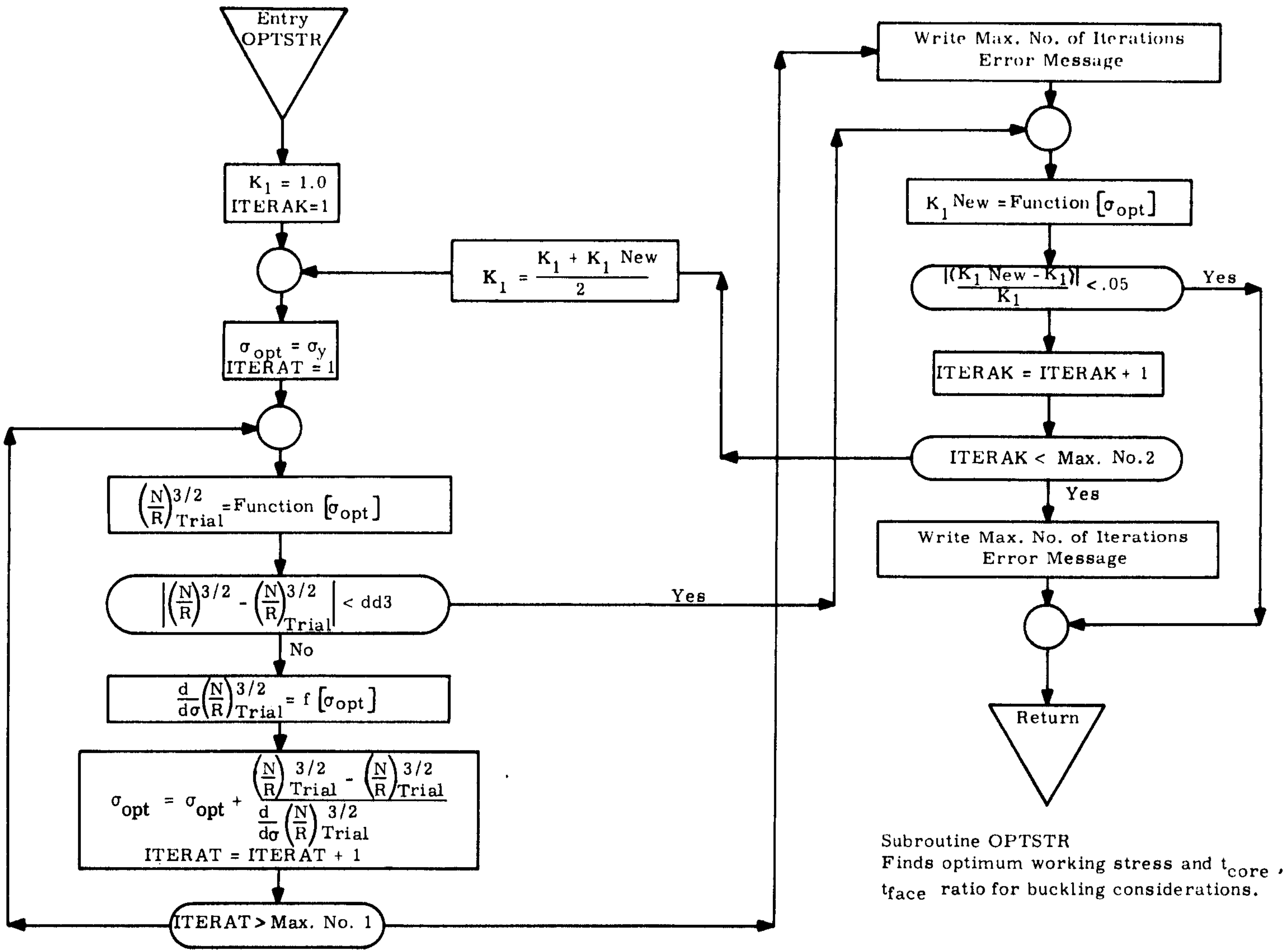


Figure 4-11. HHEAD (Sheet 2 of 2)



Subroutine OPTSTR
Finds optimum working stress and t_{core}, t_{face} ratio for buckling considerations.

Figure 4-12. OPTSTR

d. σ_{opt} = optimum working stress.

e. ITERAT = iteration counter.

f. $(N/R)^{3/2}_{trial}$ = trial value of structural index computed from σ_{opt}.

g. $(N/R)^{3/2}$ = actual value of this structural index we are trying to hit.

h. del 3 = tolerance on $(N/R)^{3/2}$ for iteration.

i. $\frac{\partial}{\partial \sigma}(N/R)^{3/2}_{trial}$ = value of $\frac{\partial[(N/R)^{3/2}]}{\partial \sigma}$ computed at σ_{opt}, used to iterate by Newton's method.

j. K_1 new = iterated value of K_1, compared against K_1 and used to compute better estimate of optimum K_1.

4.4.2.3 Subroutine SATISF

The following symbols are used:

a. IG = signal for iterated stress above allowable for local instability.

b. IL = signal for iterated stress below allowable for local instability.

c. ITERAT = iteration counter.

d. SIZDEL = current step size (tolerance).

e. σ_{opt} = input optimum stress to check for local instability.

f. σ = stress level we are checking in iteration.

g. GLT = core shear modulus under consideration.

h. d_{cor} = maximum allowable core cell diameter to prevent monocell buckling.

i. SAT = logical variable, used as signal for resisting local instability.

j. Δt_f = adjustment to make to face thickness to bring it closer to minimum allowable.

k. t_f = face thickness.

l. N_x = axial load.

4.4.2.4 Subroutine CFIND

The following symbols are used:

a. t_f = given face thickness.

b. η = tangent-secant modulus plasticity reduction factor.

c. σ = working face stress.

d. R = radius of equivalent sphere.

e. B = half of central angle subtended by head on equivalent sphere.

f. C = constant correction factor.

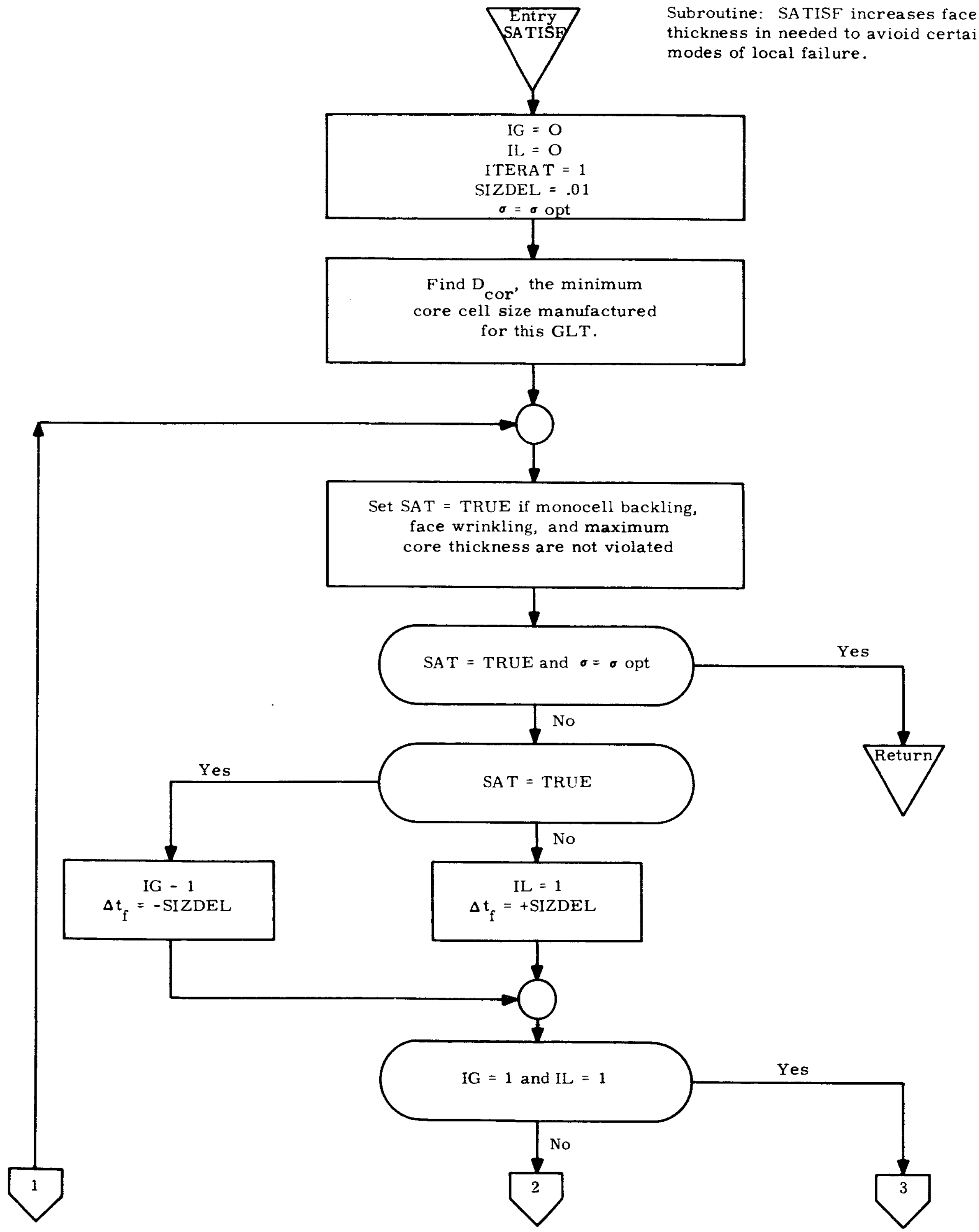


Figure 4-13. SATISF (Sheet 1 of 2)

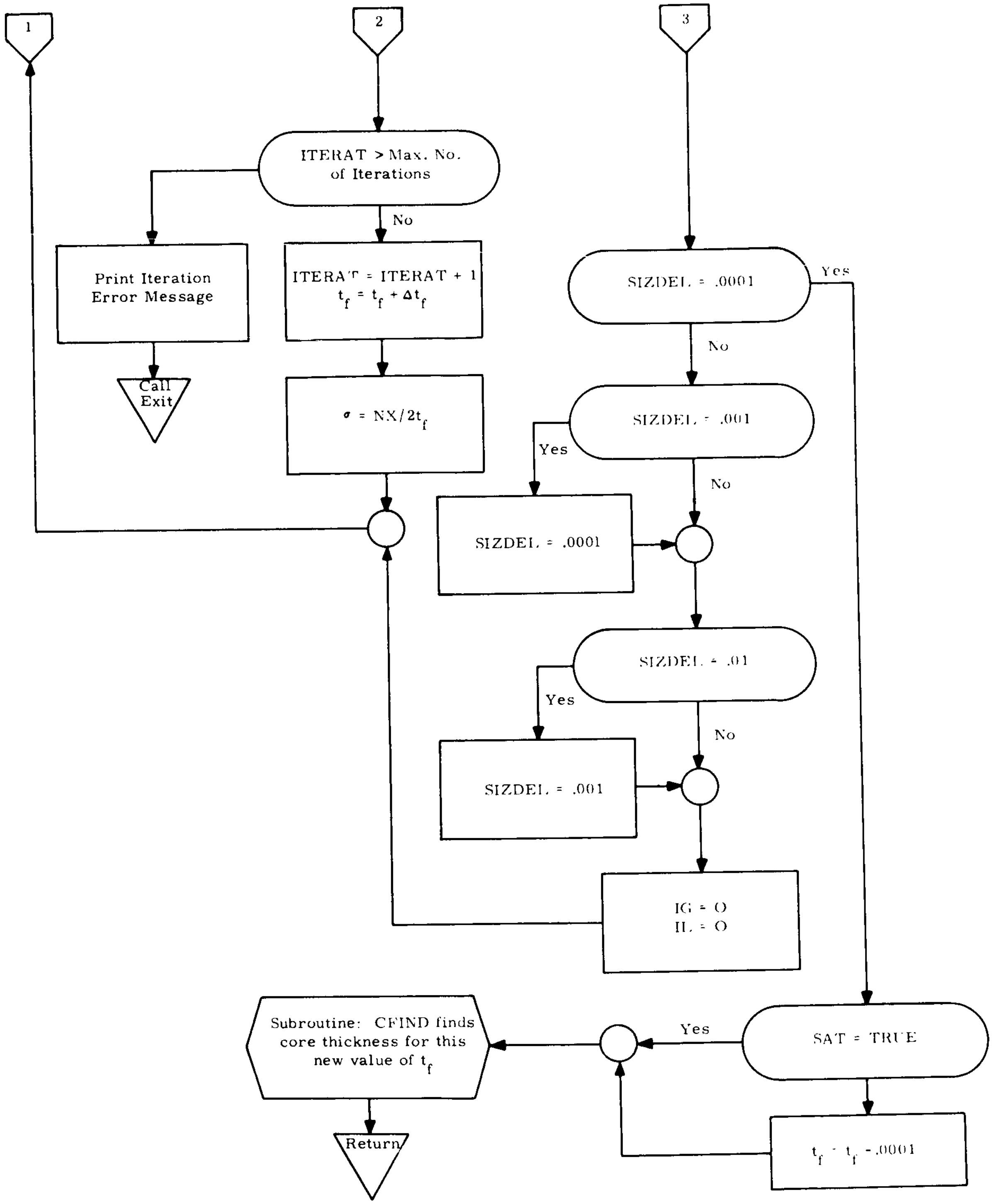


Figure 4-13. SATISF (Sheet 2 of 2)

Subroutine: CFIND finds core thickness needed for a given face and stress level, by a quadratic equation.

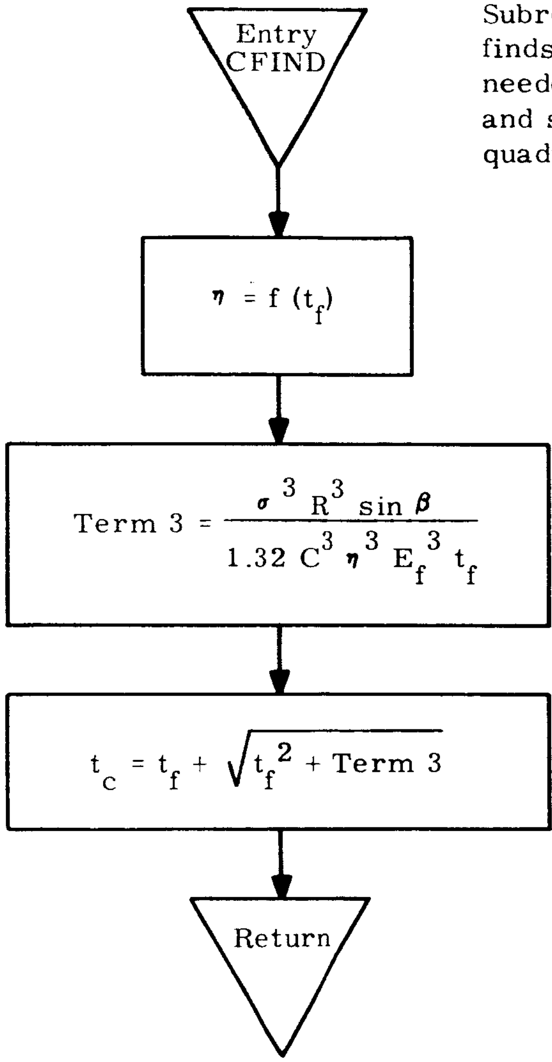


Figure 4-14. CFIND

g. E_f = Young's modulus of face material.

h. TERM3 = variable used for computational convenience.

i. t_c = core thickness.

4.4.2.5 Subroutine FFIND

The following symbols are used:

a. FLOAD = a load parameter used in iteration to find maximum allowable working stress.

b. E_f = Young's modulus of face material.

c. R = radius of equivalent sphere.

d. B = half of central angle subtended by head on equivalent sphere.

e. C = a constant correction factor.

f. DEL3 = tolerance on iteration for FLOAD.

g. σ_y = yield stress.

h. σ = trial value of maximum allowable stress in iteration.

i. ITERAT = iteration counter.

j. $FLOAD_{trial}$ = trial value of load parameter computed on basis of trial value of σ.

k. t_c = given core thickness for which to find σ.

l. DF = $\partial(FLOAD)/\partial\sigma$ = the partial of the load parameter with respect to σ.

m. t_f = face thickness computed on basis of final σ.

n. N_x = compressive axial load.

4.4.3 SPECIAL ATTENTION ITEMS

The iteration for optimum face stress level in the routine OPTSTR has proven very stable in running. However, an error return is provided in case the iteration fails to converge in the input number (MIN) of iterations.

Since the routine SATISF merely increases face thickness to the minimum that can resist local instability, its iteration is never expected to blow up. To allow for computer malfunction or incorrect input, an error return is provided if the iteration count exceeds the input maximum number (MIS).

The iteration for highest allowable face stress in subroutine FFIND has also proven very stable is running of this program, but again an error return is provided if the iteration count should exceed the input maximum (MIN).

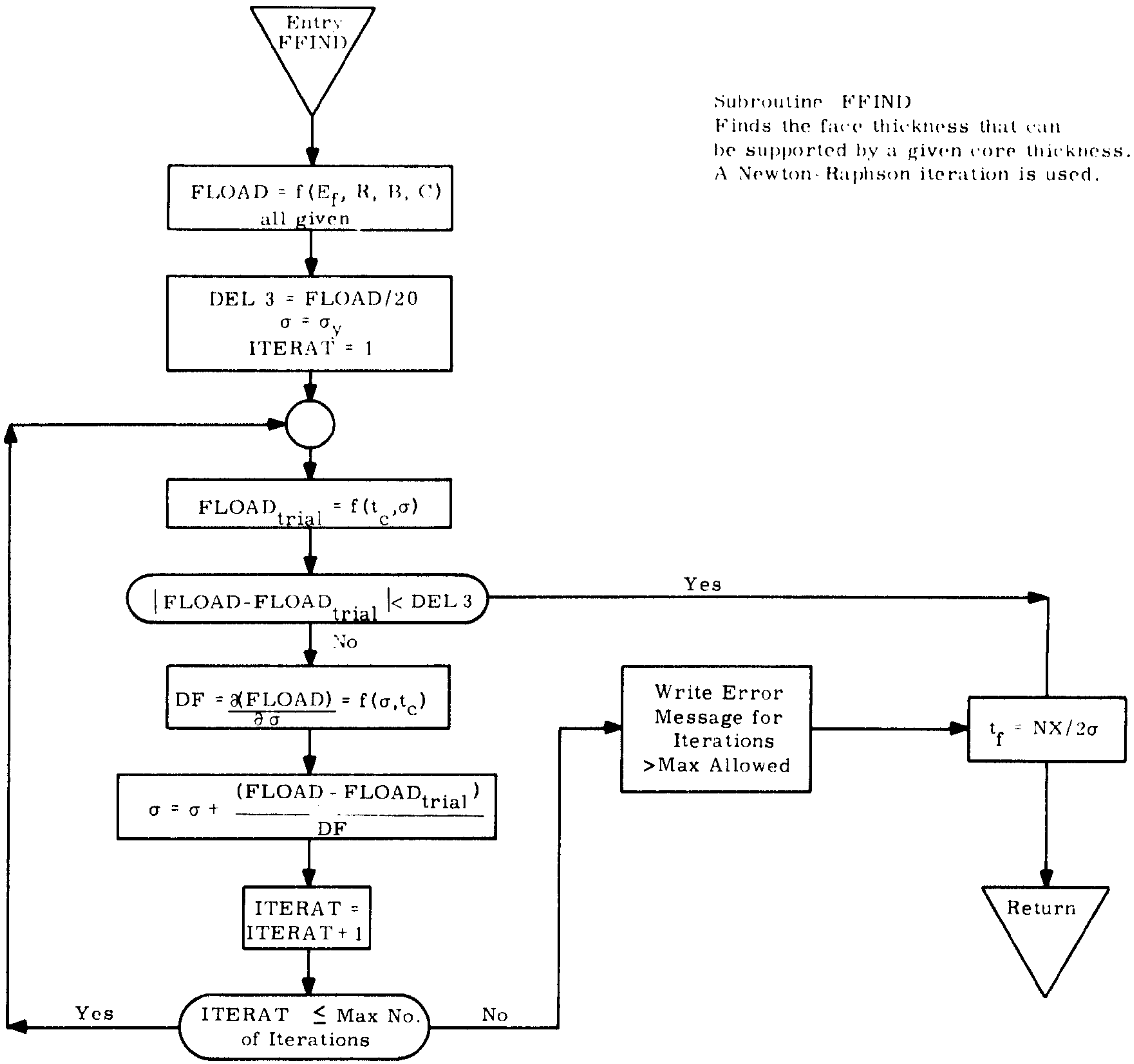


Figure 4-15. FFIND

A fatal error of not having an elliptical head tangent to the cylinder to which it is attached is tested for. This error causes exit to be called. However, this error should never occur if input to the stress program is correct.

4.5 45-DEGREE WAFFLE

4.5.1 SUMMARY

The function of the waffle stiffened subroutine is to design an optimum cylindrical or conical structure with strength and buckling as governing criteria. Conical sections are analyzed by treating them as a cylinder of equivalent length and radius. The program will determine the following optimum design parameters by:

a. Skin thickness (TS).
b. Rib thickness (TWS).
c. Rib spacing (BS).
d. Overall depth (H).

4.5.2 PROGRAM DESCRIPTION

The program first calculates a strength/weight ratio as a function of C1, C2, and C3 (see Table 4-1) and picks a maximum ratio. This ratio is checked to see if all conditions are satisfied (general instability, local panel buckling, rib crippling, rib spacing, and HMAX). If all conditions are satisfied on optimum design is achieved and a return to the main program is made to check for type of case. If an optimum design is not achieved, the next largest value is selected and the program is repeated until no condition is violated.

The program then checks for a buckling or strength governed case. If it is a buckling governed case the design parameters are calculated and a check for minimum gage is made. If the design is satisfactory the weight is calculated. If minimum gage is set the iteration scheme is used to increase C3 so the same buckling strength design parameters and weight are then calculated. If it is a strength governed case the following procedure is used:

a. Increase depth (H).
b. Check if H is greater than HMAX.
c. Calculate design parameters.
d. Check for minimum gage. If it is satisfactory, calculate weight.
e. If minimum gage is set the iteration scheme is used to increase C3 to achieve equal strength.

f. Check general instability panel buckling, rib crippling. If all is satisfied calculate design parameters and total weight and exit from program.

g. If values are not satisfied decrease C3 for rib spacing, calculate design parameters and total weight and exit from program.

The 45-degree waffle subroutine is also provided with the option to specify the overall depth or the rib spacing. Given one of these options the other three design parameters are chosen such that an optimum design results. Basically the same procedure is used as that previously described with the exception that the optimization is performed with three parameters rather than four.

Table 4-1

Parameters Built Into Program 45-Degree Waffle

1. General Waffle 45-Degree Procedure					
C1	0.1	0.11	0.12	0.13	0.14
C2	0.05	0.10	0.15	0.20	0.25
C3	5.0	7.0	9.0	11.0	13.0
2. Depth (H) Option					
C1	0.10	0.11	0.12	0.13	0.14
C3	5.0	7.0	9.0	11.0	13.0
3. Rib Spacing Option (BS)					
C6	0.00772	0.01279	0.01786	0.02293	0.028
C7	0.00384	0.01538	0.02692	0.03846	0.05

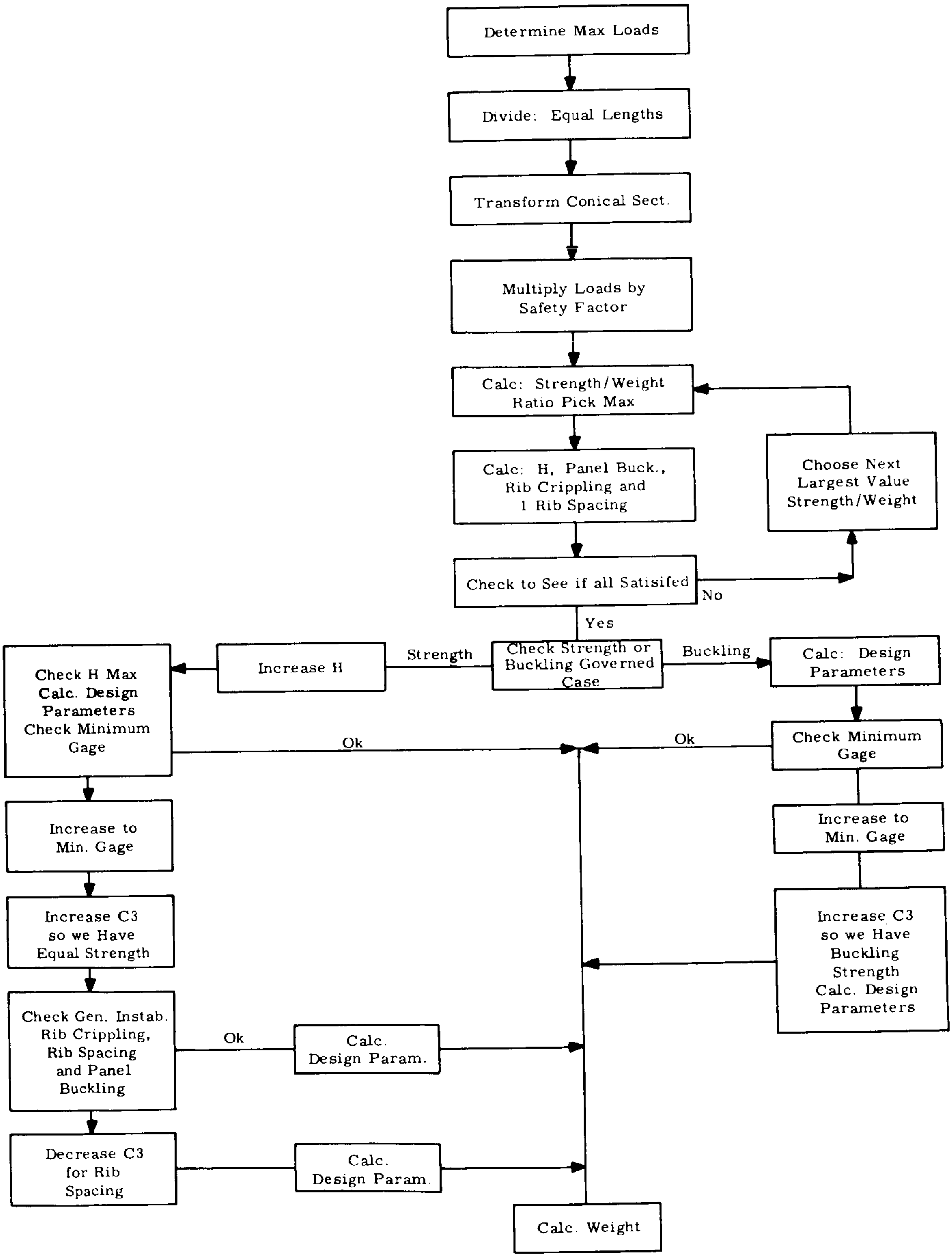


Figure 4-16. General Flow Chart for 45-Degree Waffle Stiffened Subprogram

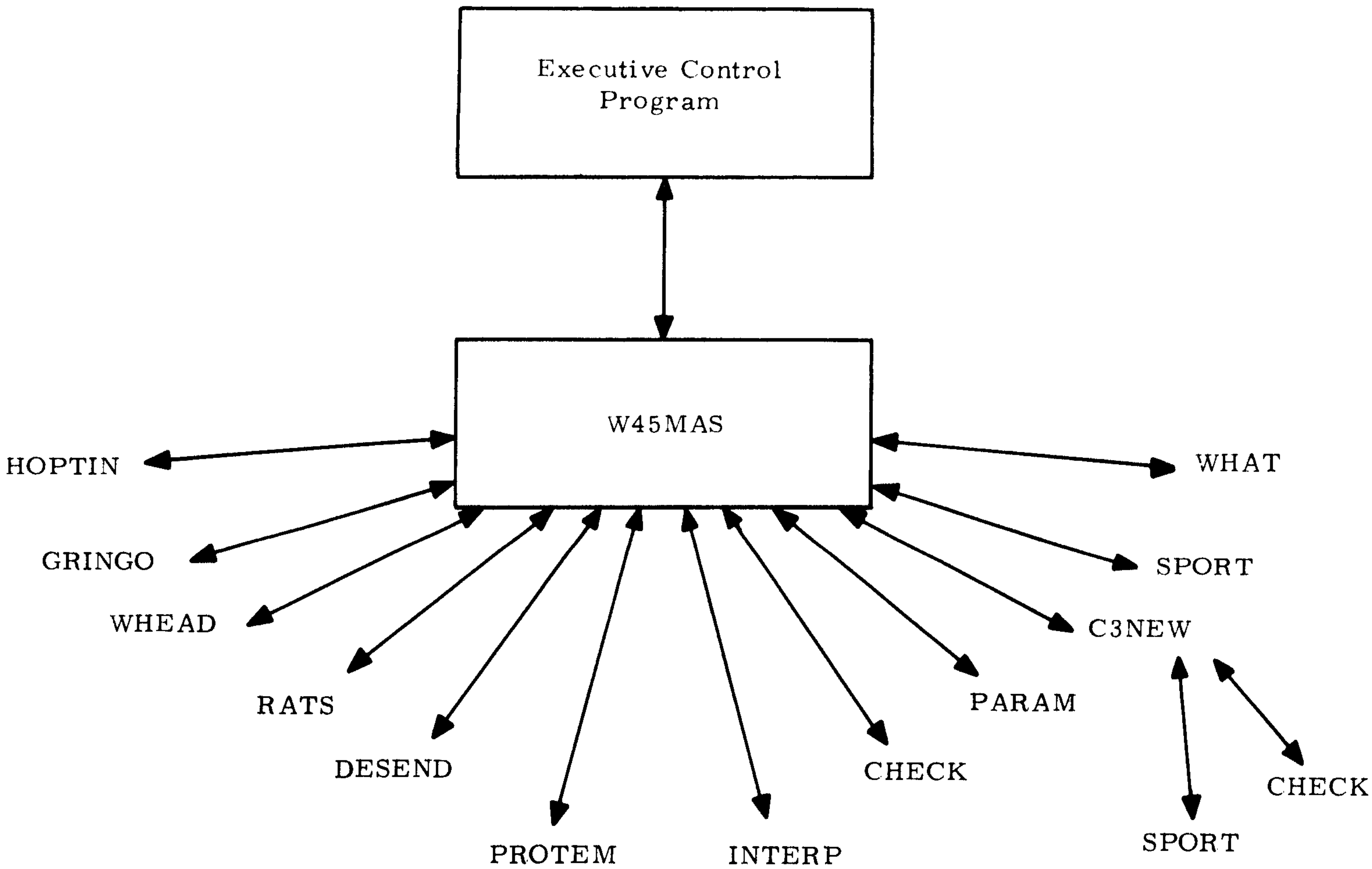


Figure 4-17. W45MAS

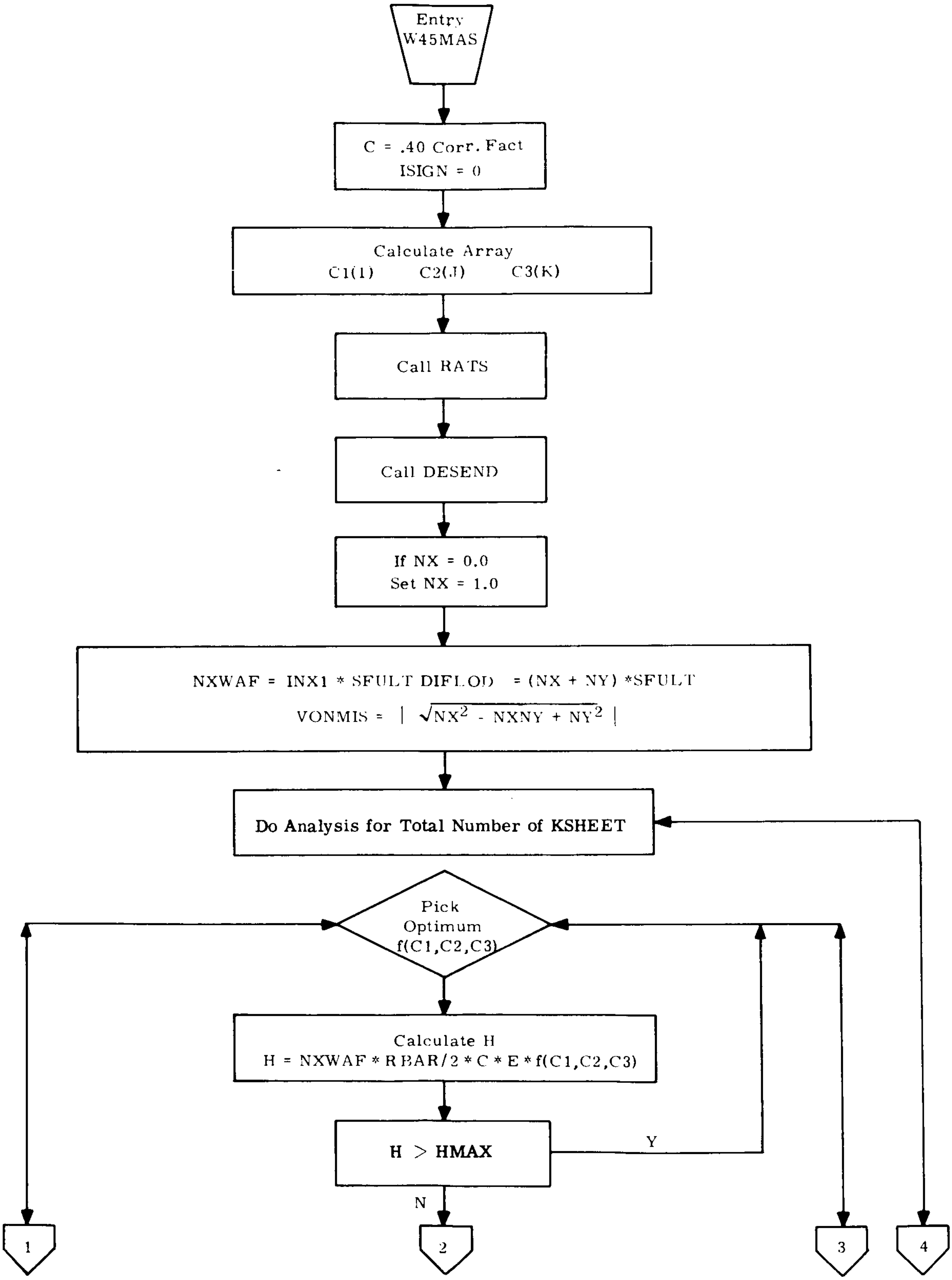


Figure 4-18. W45MAS Flow Chart (Sheet 1 of 3)

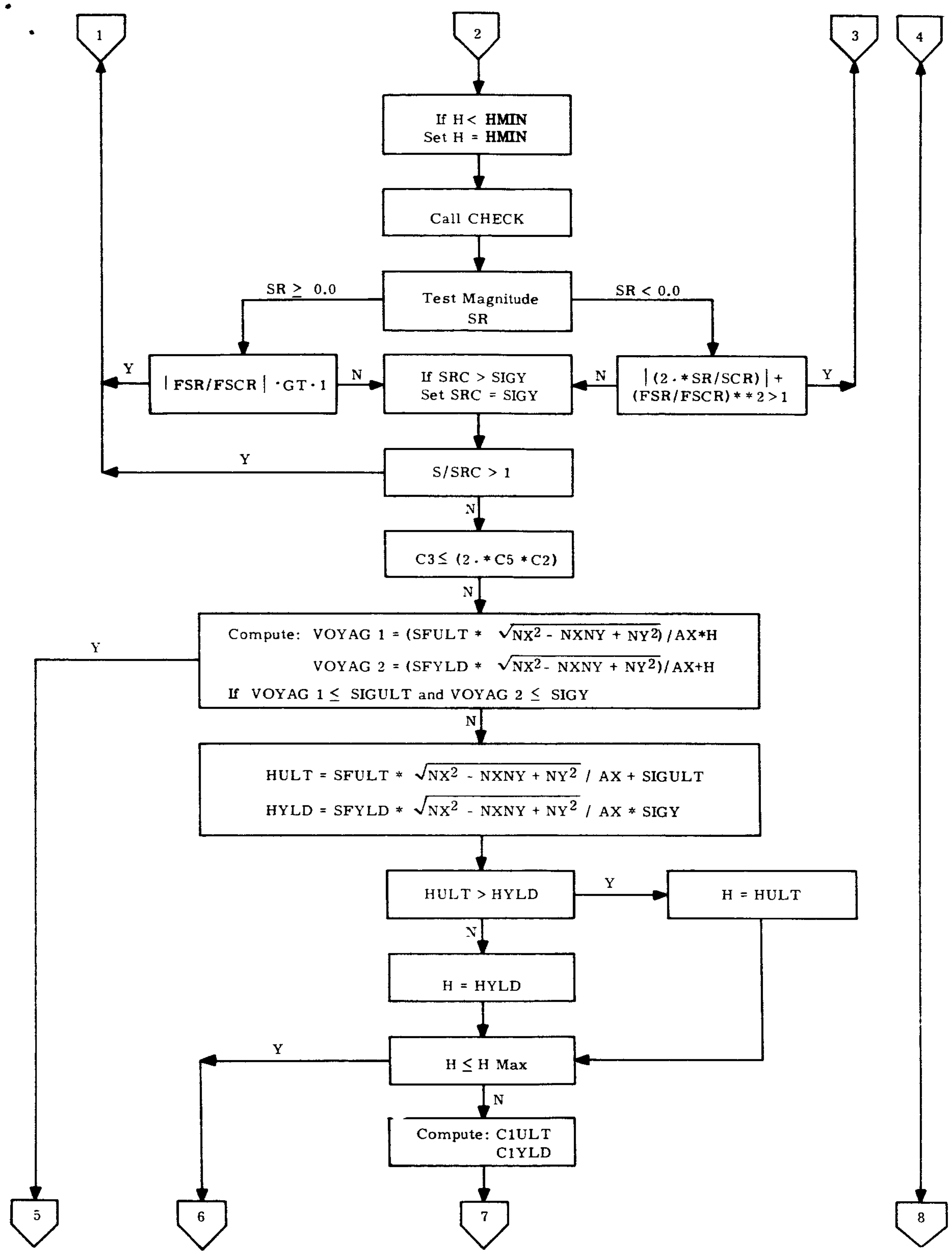


Figure 4-18. W45MAS Flow Chart (Sheet 2 of 3)

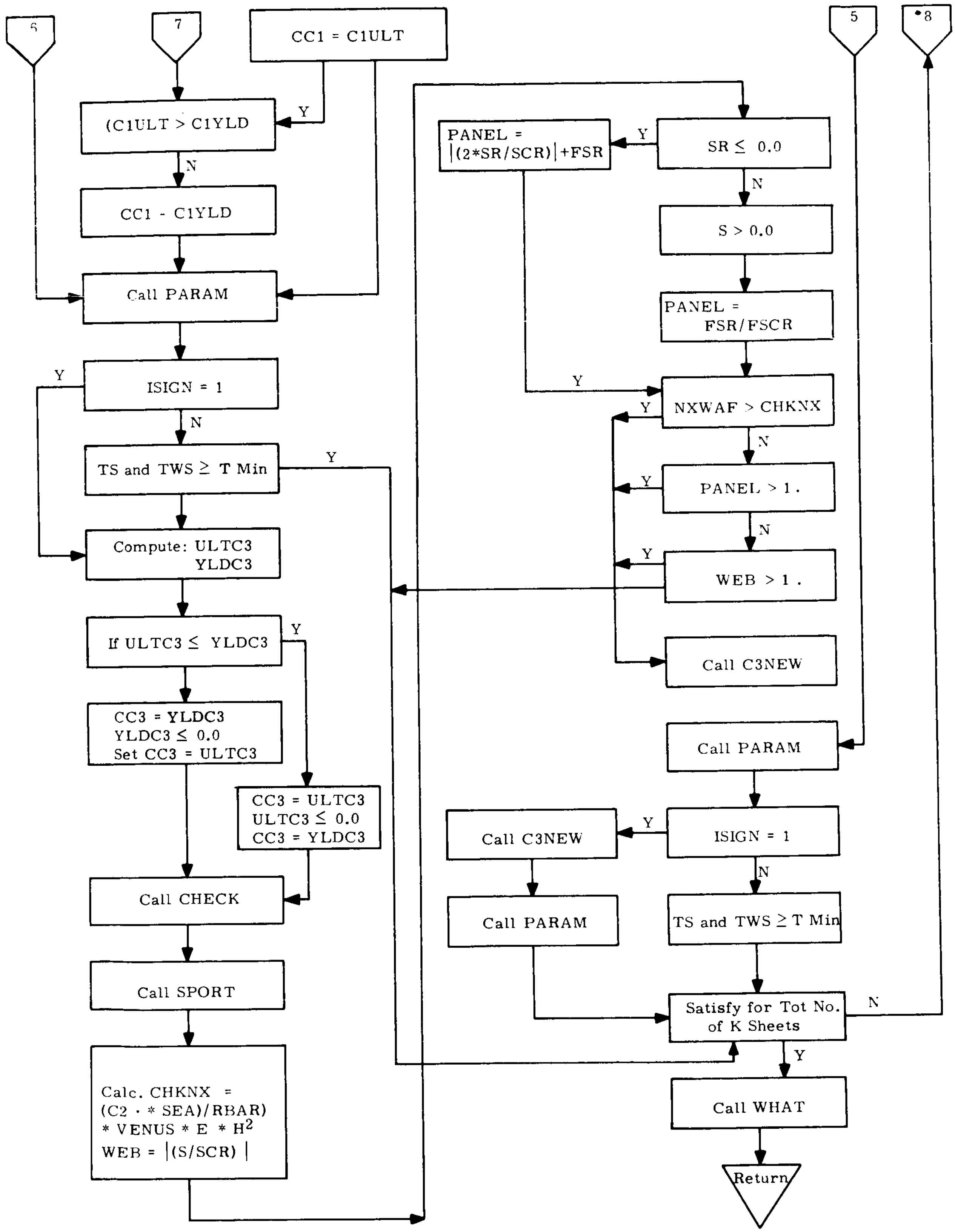


Figure 4-18. W45MAS Flow Chart (Sheet 3 of 3)

DIMENSIONED VARIABLES

SYMBOL	STORAGES	SYMBOL	STORAGES	SYMBOL	STORAGES	SYMBOL	STORAGES	SYMBOL	STORAGES
LIMIT	10,15								

Figure 4-19. 8CNEW Subroutine Flow Chart (Sheet 1 of 3)

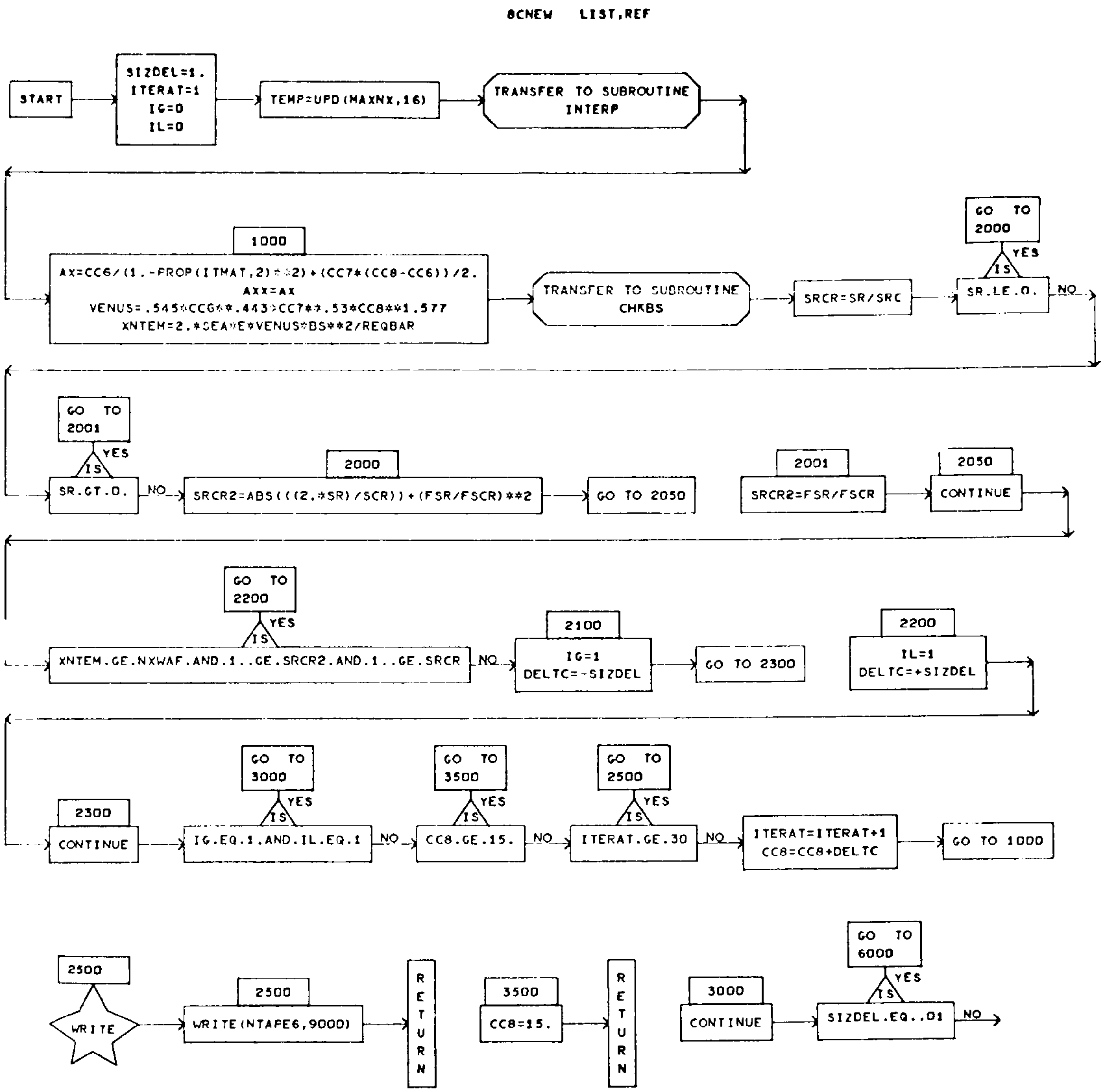


Figure 4-19. 8CNEW Subroutine Flow Chart (Sheet 2 of 3)

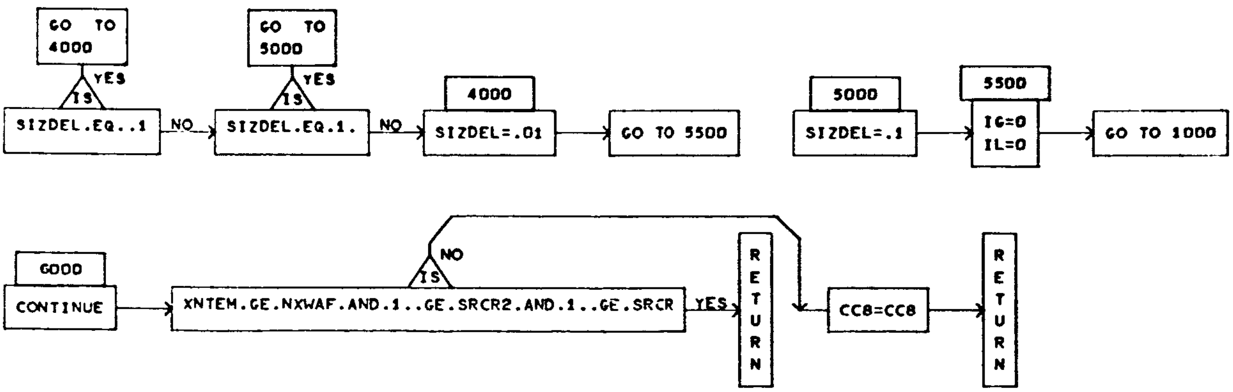


Figure 4-19. 8CNEW Subroutine Flow Chart (Sheet 3 of 3)

DIMENSIONED VARIABLES

SYMBOL	STORAGES	SYMBOL	STORAGES	SYMBOL	STORAGES	SYMBOL	STORAGES	SYMBOL	STORAGES
LIMIT	10,15	QUEEN	10,10	STAIR	25	ISTAIR	25	C1	5
C2	5,5	C3	5	CC123	5,5	NC	200		

Figure 4-20. HOPOUT Subroutine Flow Chart (Sheet 1 of 3)

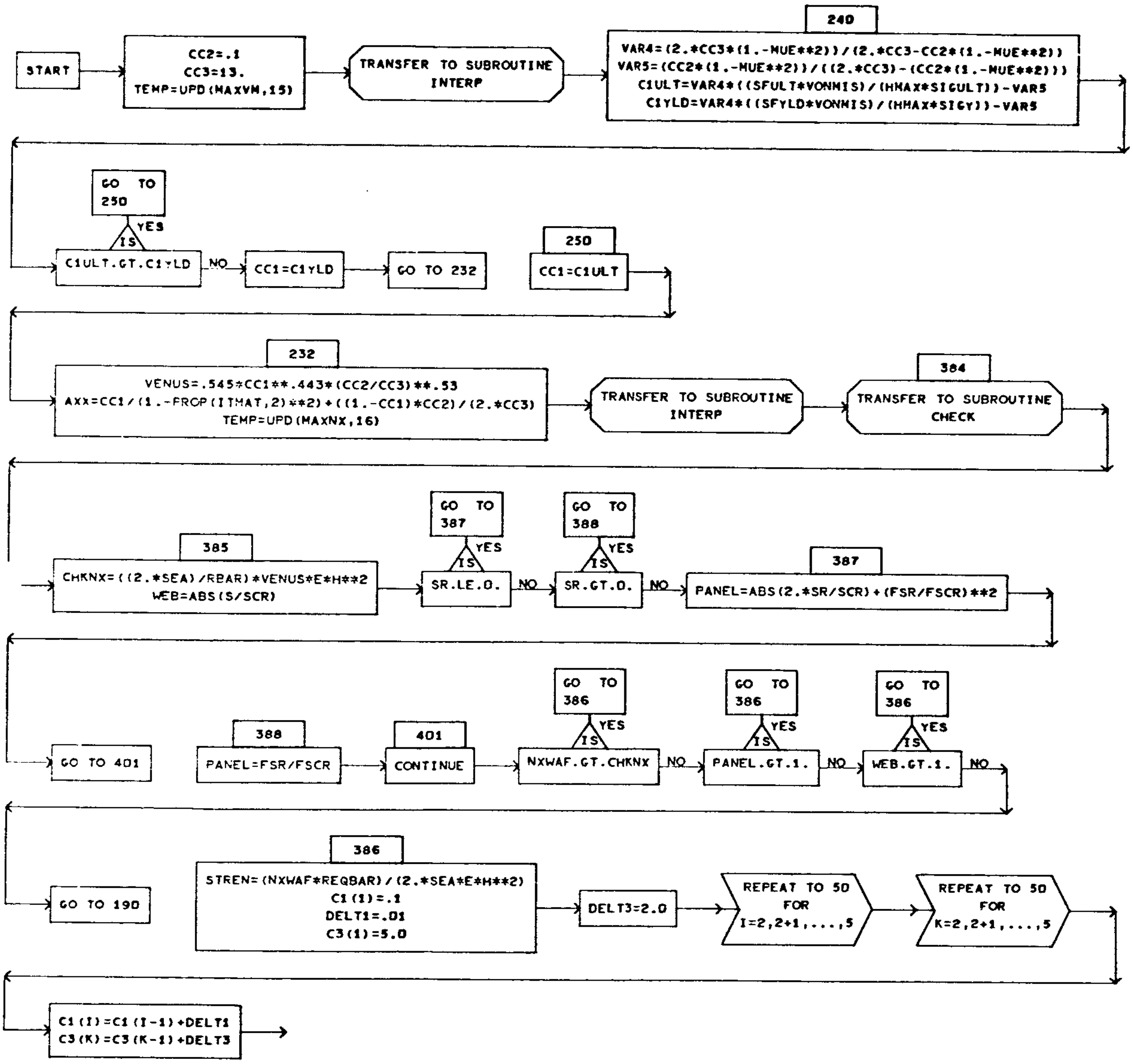


Figure 4-20. HOPOUT Subroutine Flow Chart (Sheet 2 of 3)

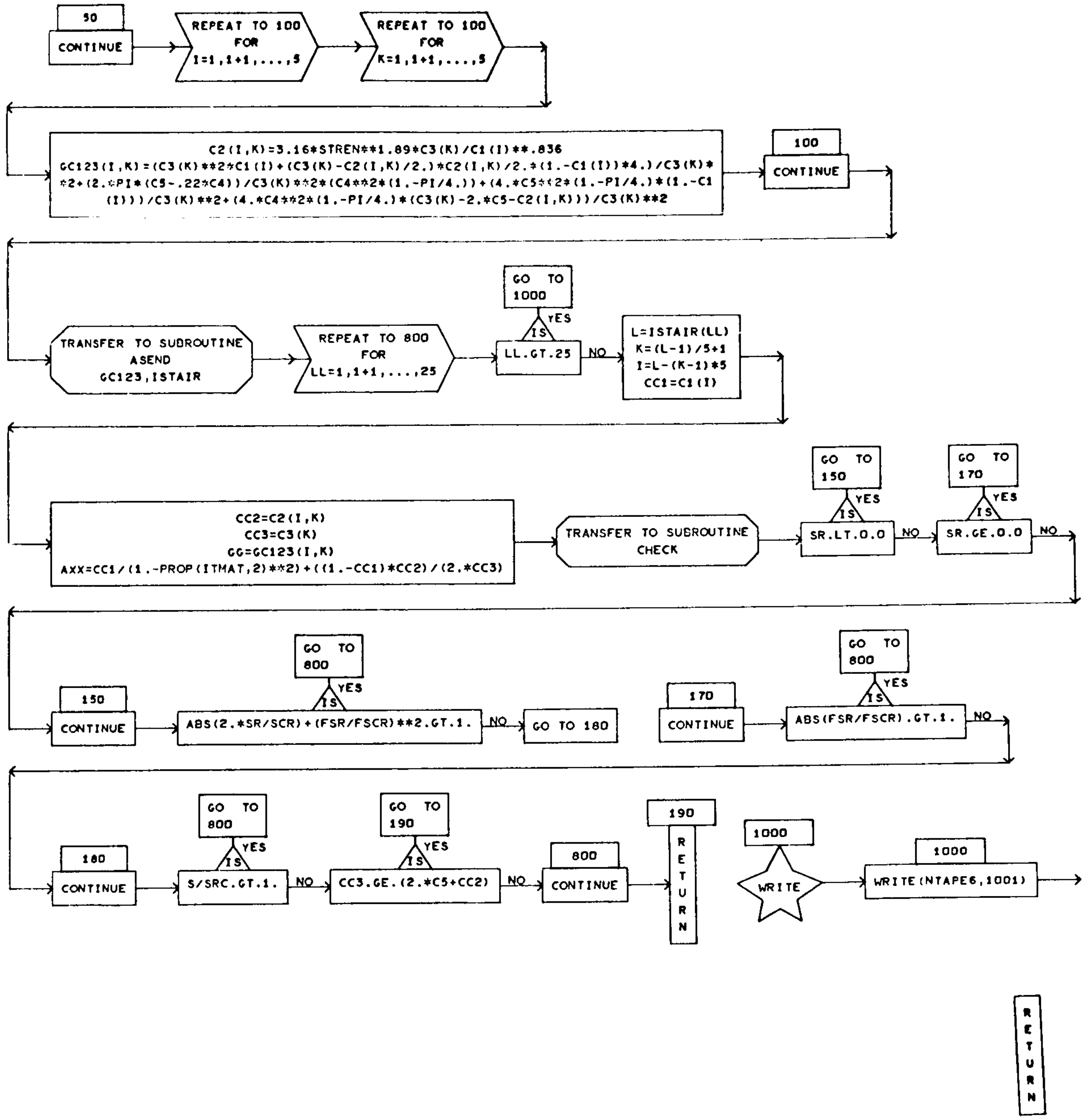


Figure 4-20. HOPOUT Subroutine Flow Chart (Sheet 3 of 3)

D I M E N S I O N E D   V A R I A B L E S

SYMBOL	STORAGES	SYMBOL	STORAGES	SYMBOL	STORAGES	SYMBOL	STORAGES	SYMBOL	STORAGES
NC	200	LIMIT	10,15	QUEEN	10,10				

Figure 4-21. 8CNU Subroutine Flow Chart (Sheet 1 of 3)

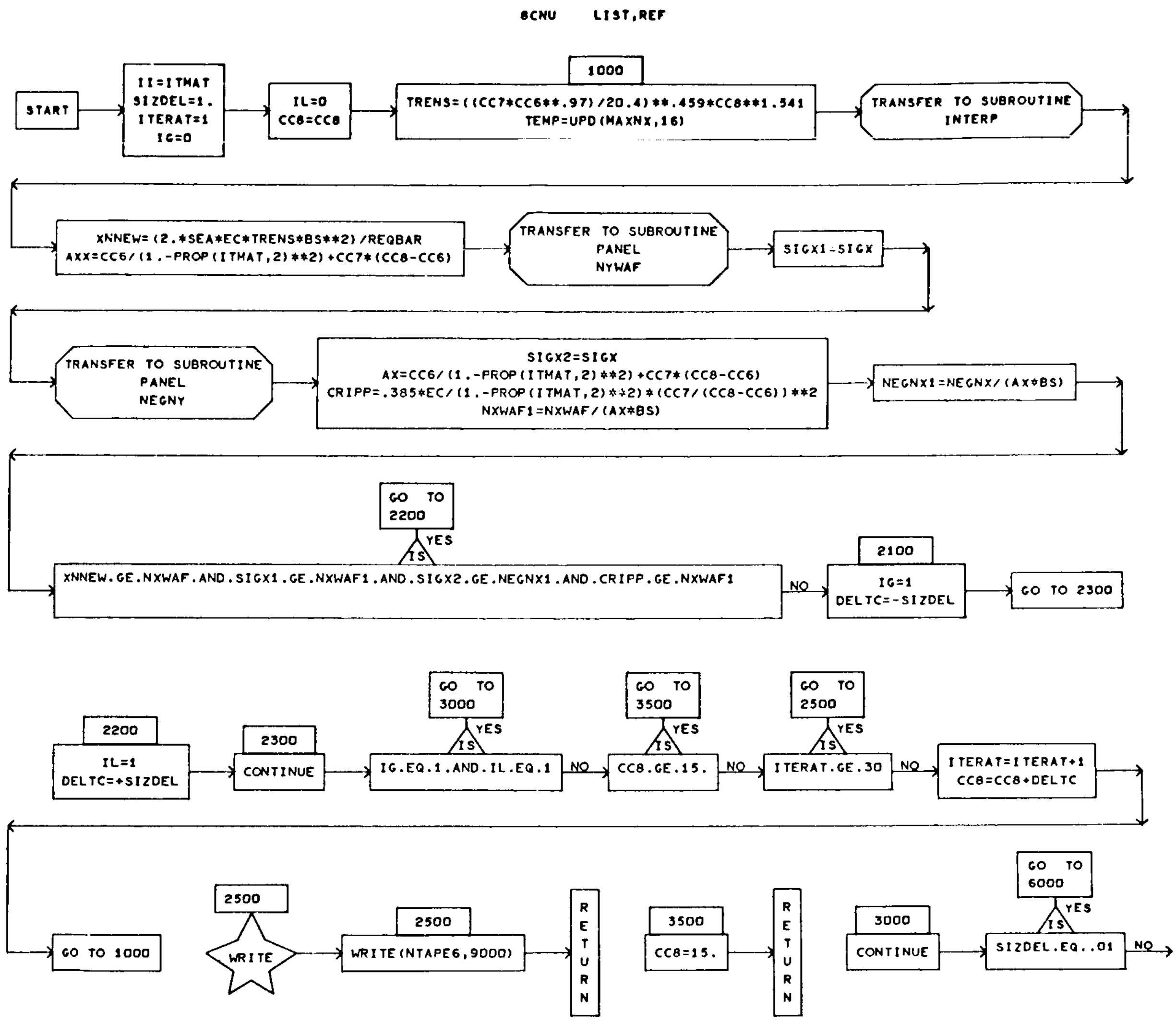


Figure 4-21. 8CNU Subroutine Flow Chart (Sheet 2 of 3)

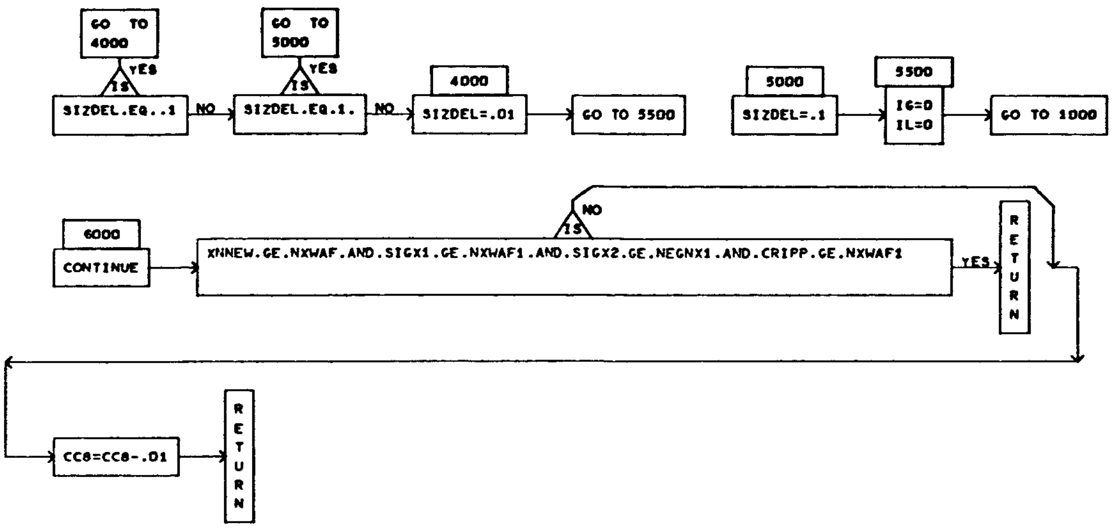


Figure 4-21. 8CNU Subroutine Flow Chart (Sheet 3 of 3)

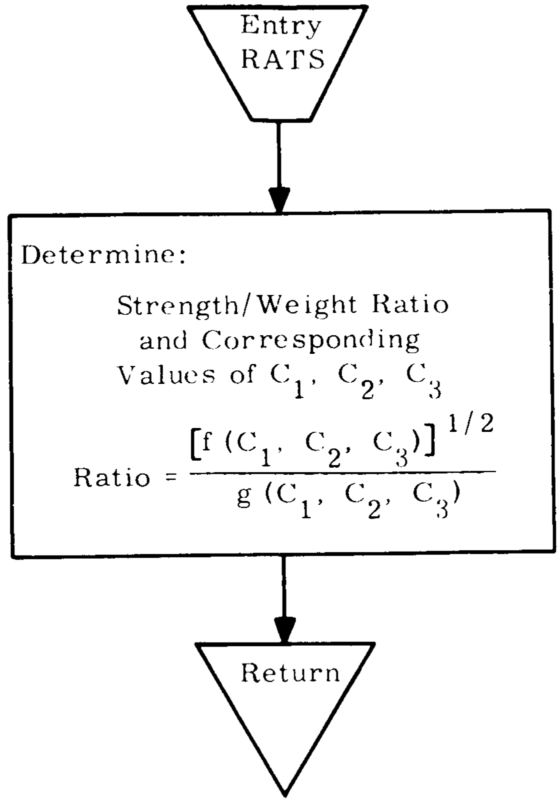


Figure 4-22. RATS Subroutine Flow Chart

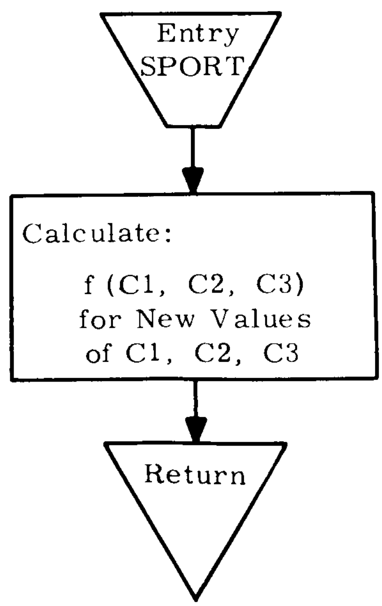


Figure 4-23. SPORT Subroutine Flow Chart

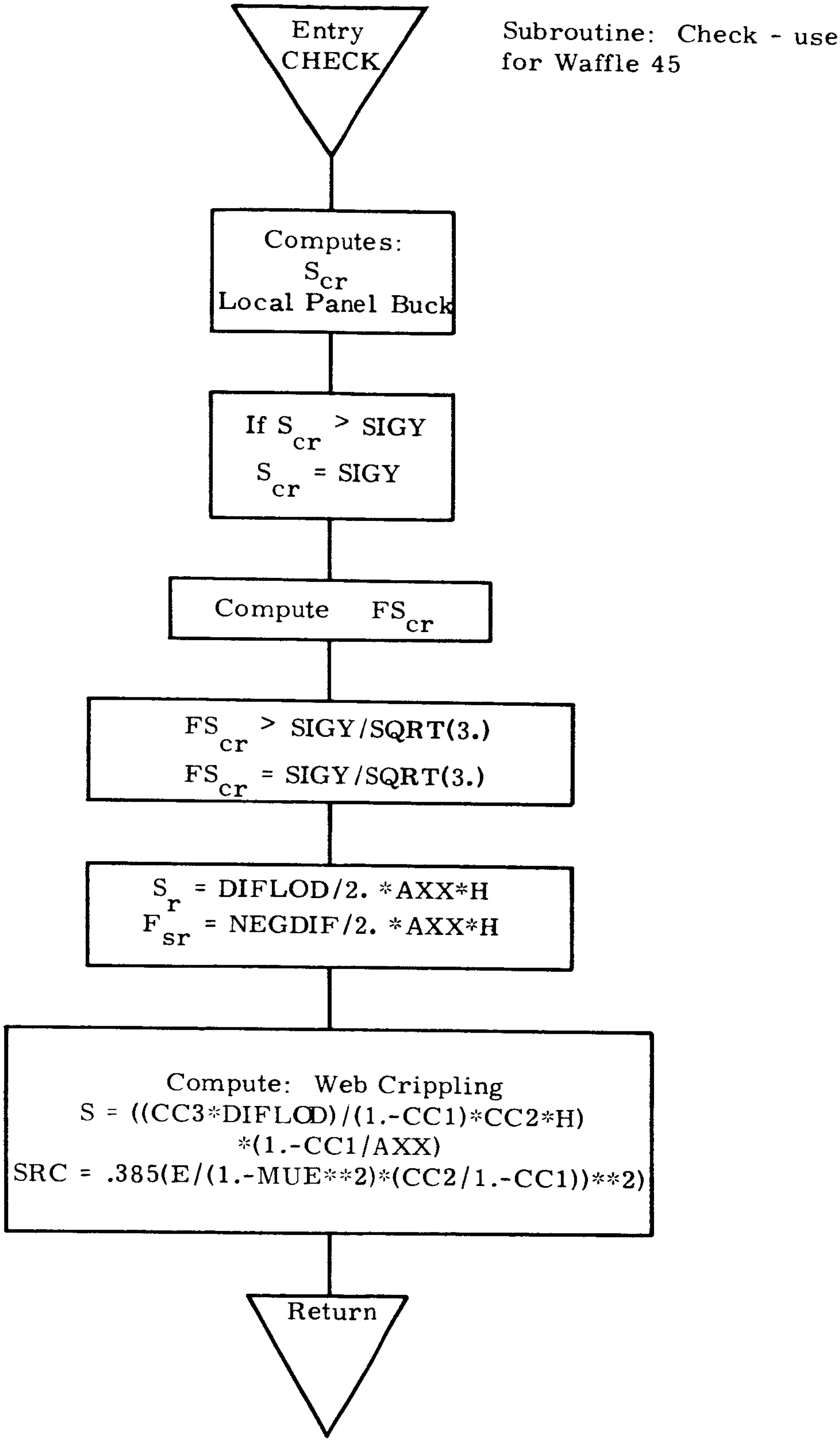


Figure 4-24. CHECK Subroutine Flow Chart

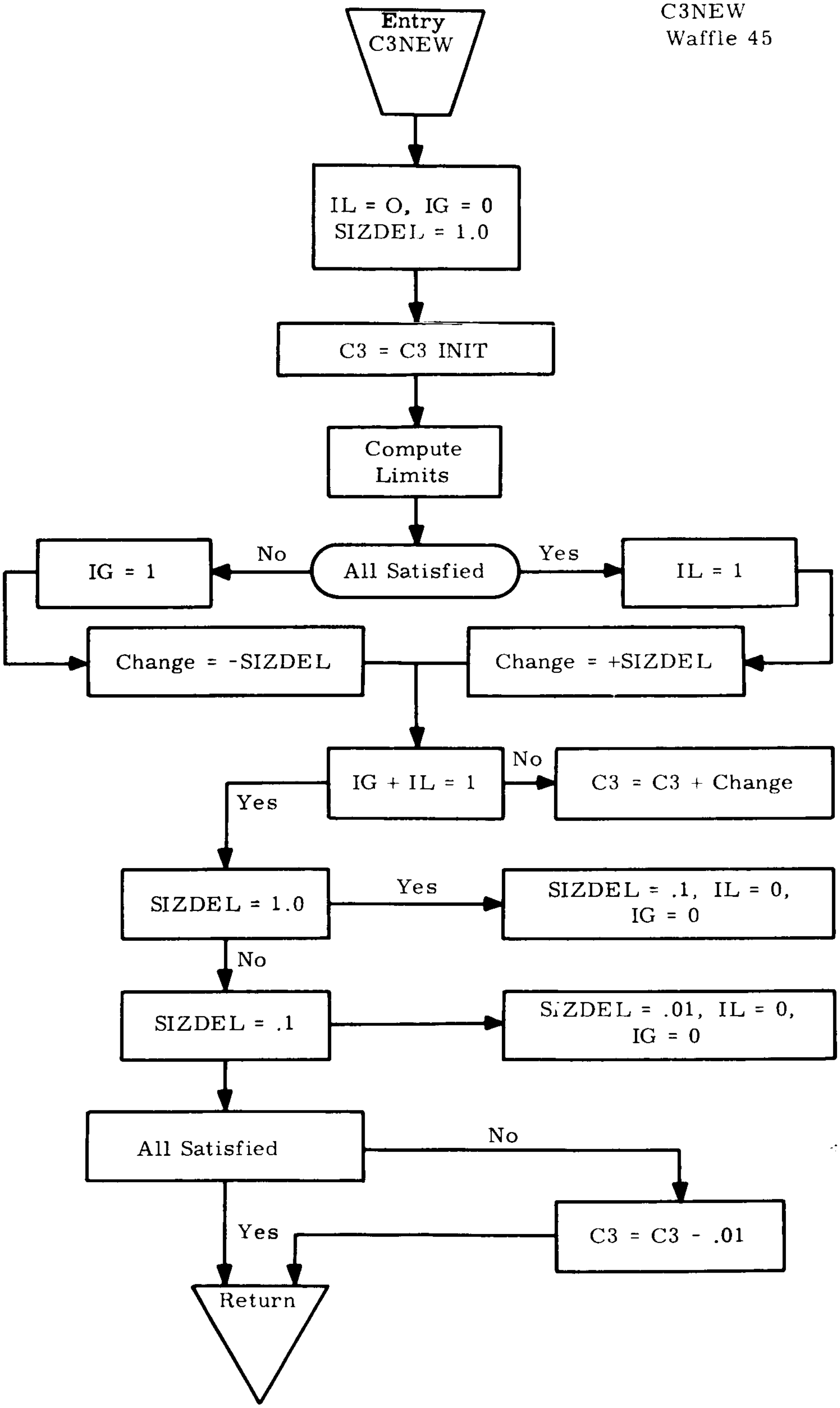


Figure 4-25. C3NEW Subroutine Flow Chart

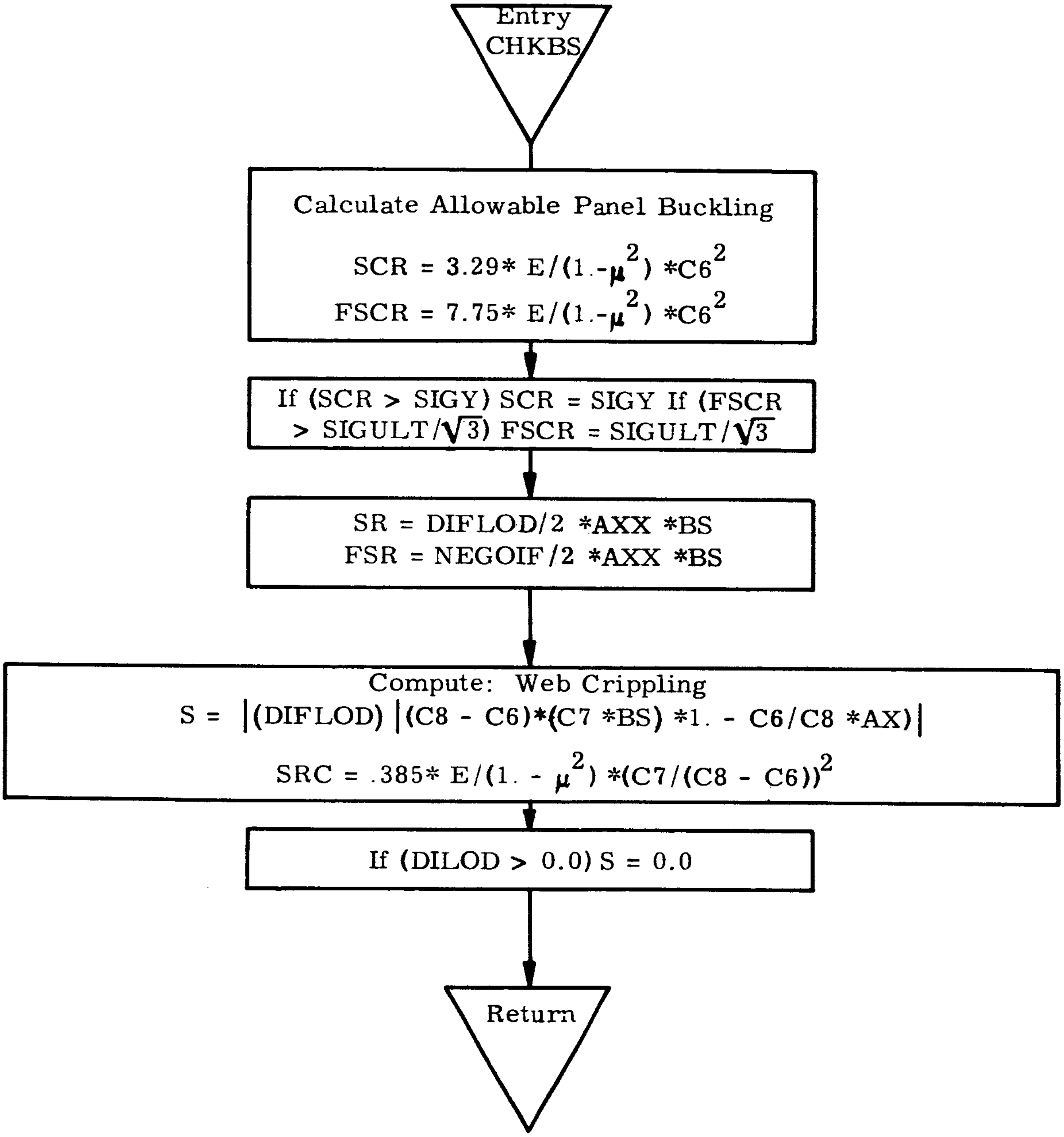


Figure 4-26. CHKBS Subroutine Flow Chart

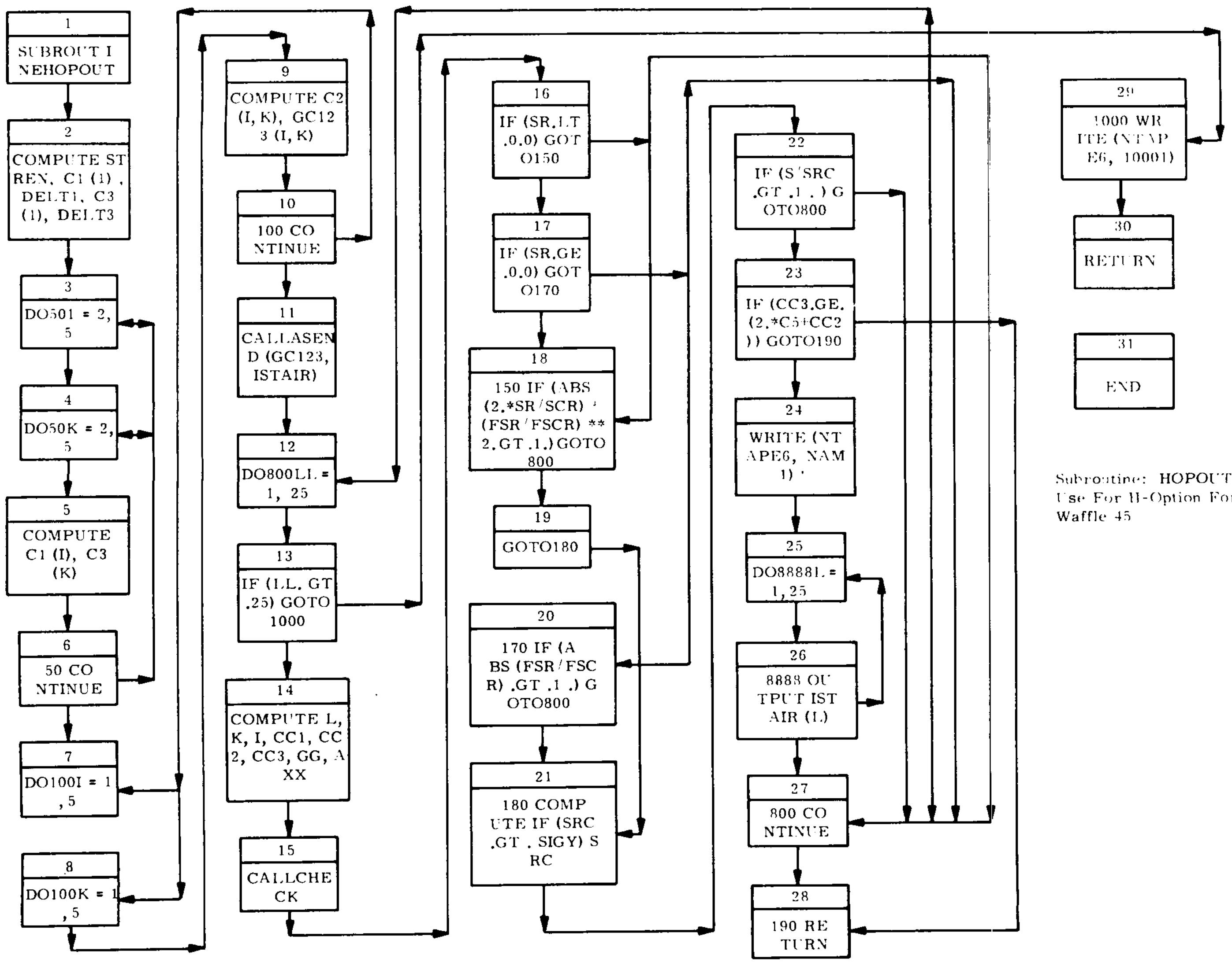


Figure 4-27. HOPOUT Subroutine Flow Chart

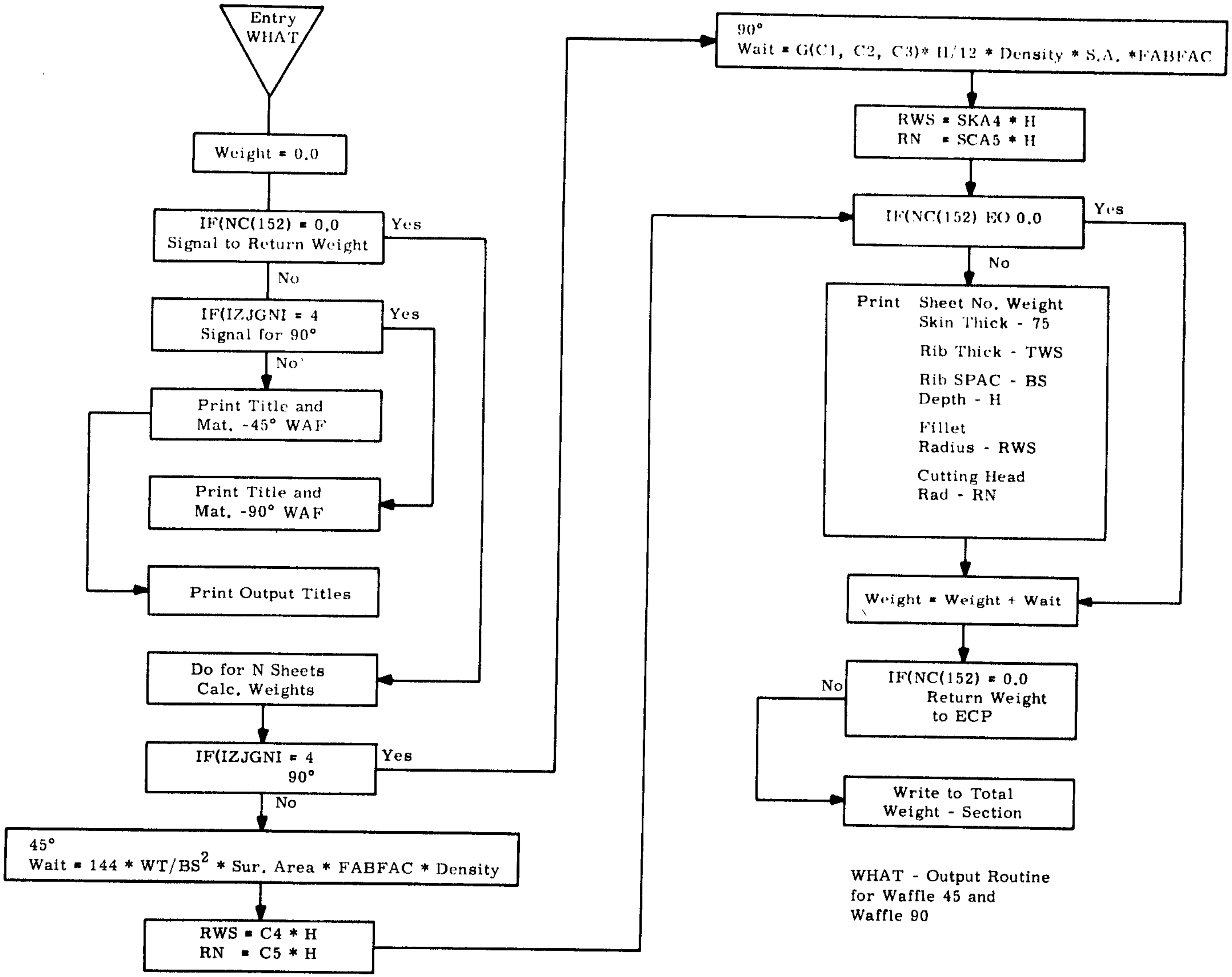
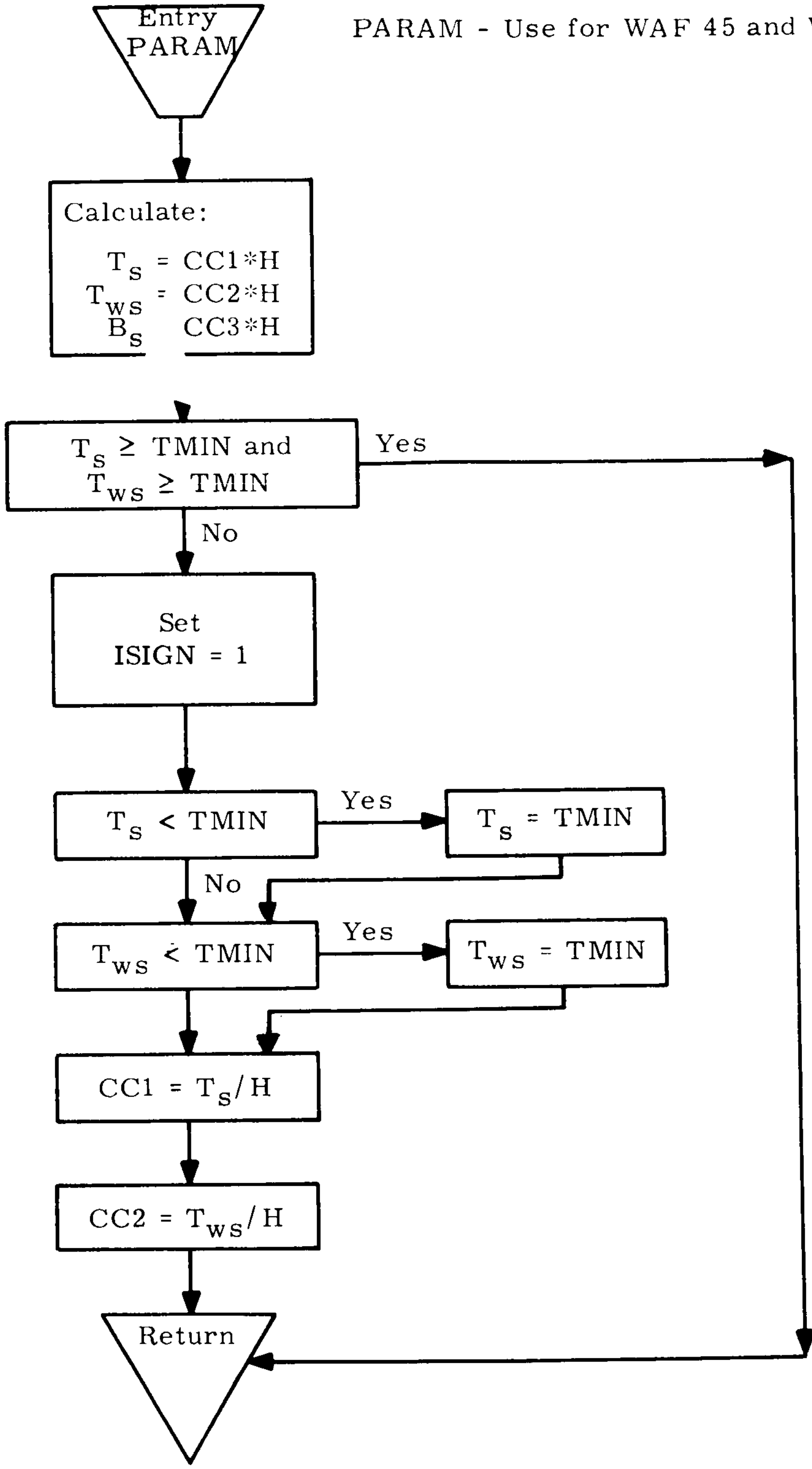


Figure 4-28. WHAT Subroutine Flow Chart



PARAM - Use for WAF 45 and WAF 90

Figure 4-29. PARAM Subroutine Flow Chart

DESEND - Use for Waffle 45 and Waffle 90

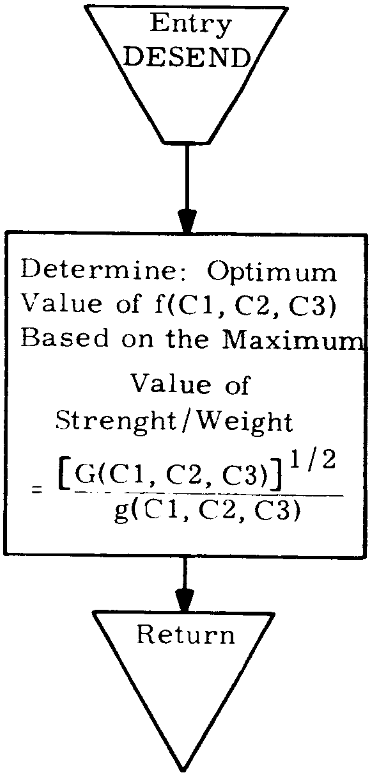


Figure 4-30. DESEND Subroutine Flow Chart

Subroutine: ASEND - use for H-Option and 35- Option on Waffle 45 and Waffle 90

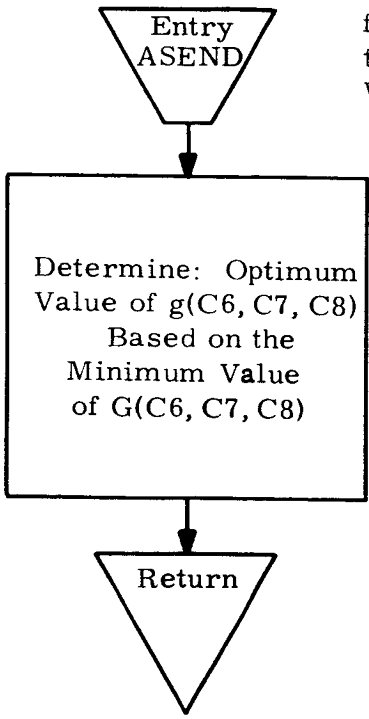


Figure 4-31. ASEND Subroutine Flow Chart

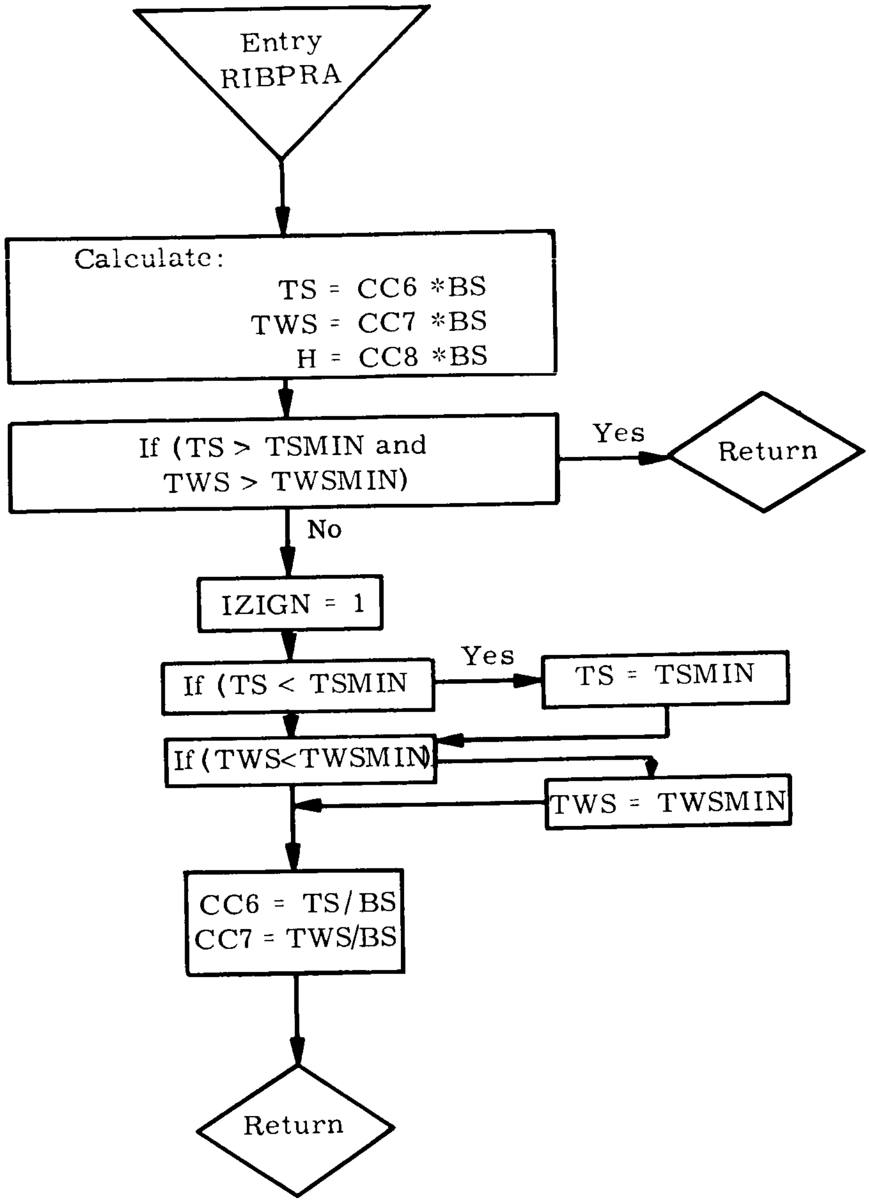


Figure 4-32. RIBPRA Subroutine Flow Chart

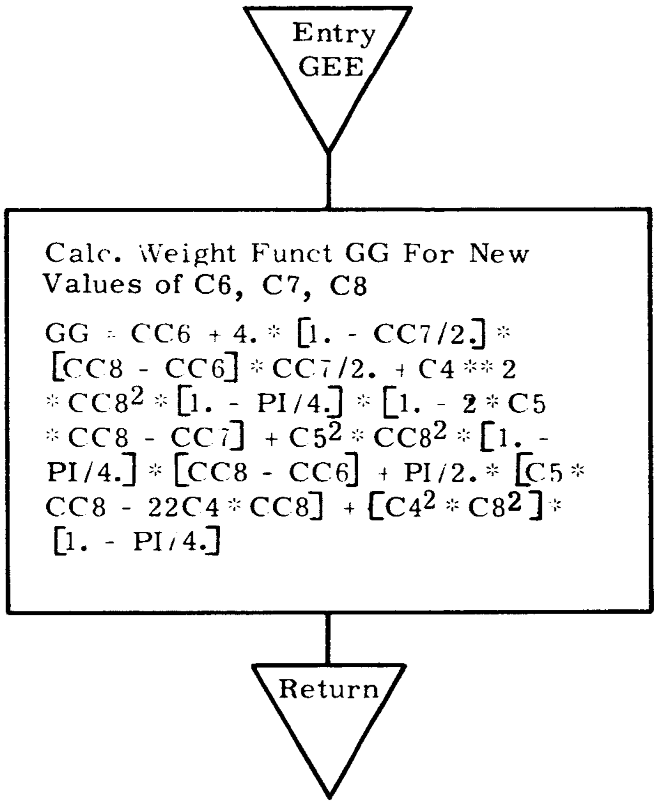


Figure 4-33. GEE Subroutine Flow Chart

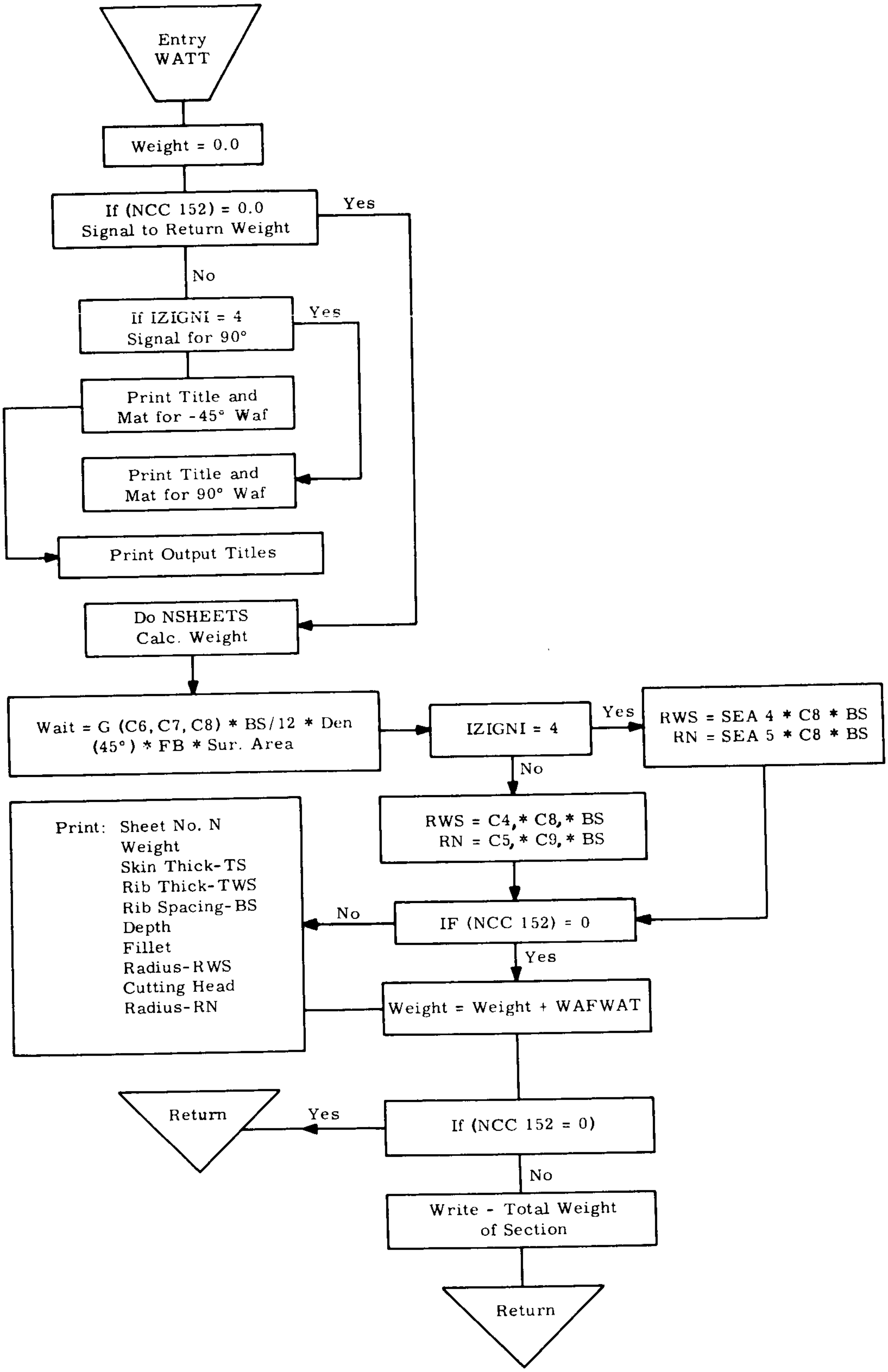


Figure 4-34. WATT Subroutine Flow Chart

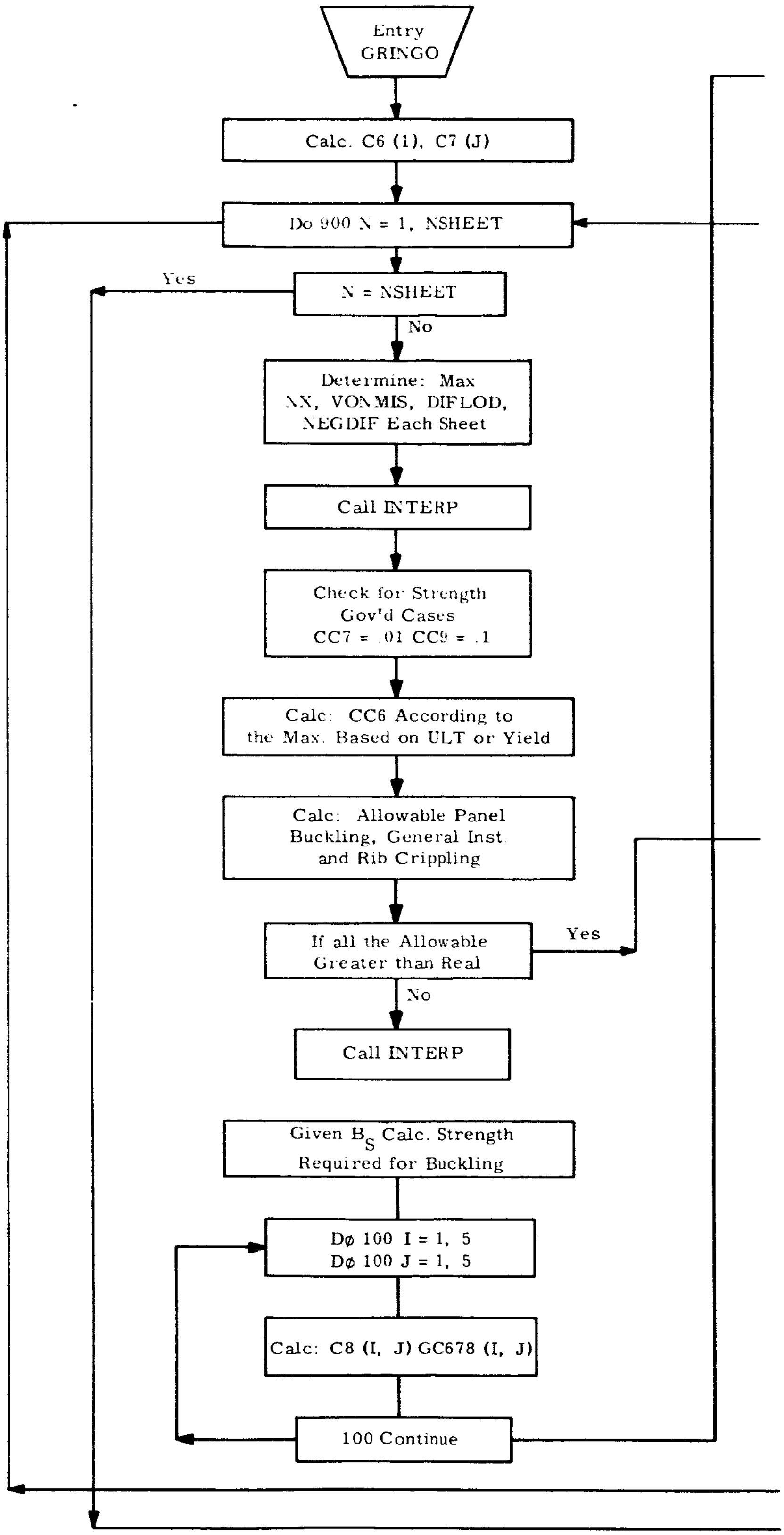


Figure 4-35. GRINGO Subroutine Flow Chart (Sheet 1 of 2)

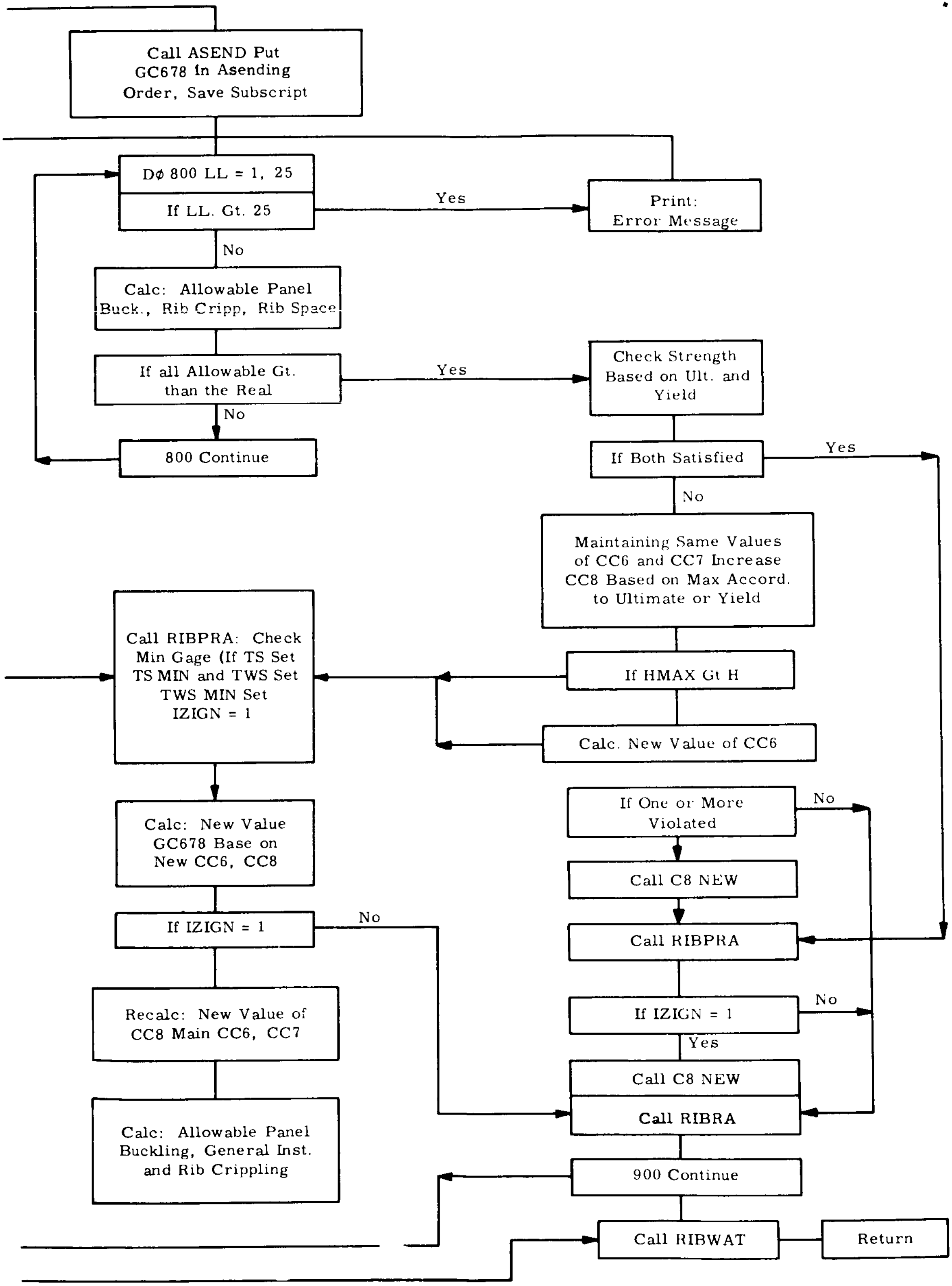


Figure 4-35. GRINGO Subroutine Flow Chart (Sheet 2 of 2)

4.6 SUMMARY OF SUBROUTINES

4.6.1 W45MAS

Main subroutine to establish a method for optimizing 45-degree waffle for each section of the vehicle. Analysis is done for both strength- and buckling-governed cases.

4.6.2 RATS

Computes strength-to-weight ratio based on C1, C2, C3 that are built into the program for 45-degree waffle.

4.6.3 CHECK

Calculates allowable panel buckling due to compressive or tension forces whichever the case may be. Also calculates allowable rib crippling for 45-degree waffle.

4.6.4 C3NEW

Reduces the value of C3 in increments of 1.0, 0.1, and 0.01 until general instability panel buckling, and web crippling are satisfied for 45-degree waffle.

4.6.5 SPORT

Recalculates new value of strength/weight due to the changes incurred in C1 and C3 in the program.

4.6.6 C8NEW

Iteration routine which reduces or increases C8 in increments of 1.0, 0.1, and 0.01 until conditions are satisfied. Use for rib spacing option for 45-degree waffle.

4.6.7 HOPOUT

Option to specify overall depth for 45-degree waffle.

4.6.8 GRINGO

Option to specify rib spacing for 45-degree waffle.

4.6.9 CHKBS

Calculates panel buckling, rib crippling for rib spacing option for 45-degree waffle.

4.6.10 GEE

Calculates weight function for new values of C6, C7, and C8 for 45-degree waffle rib spacing option.

4.6.11 WHAT

Output routine for both 45-degree and 90-degree waffle. Calculates and prints (1) fillet head radius and cutting head radius, (2) weight of each sheet, and (3) total weight of section. Prints skin thickness, web thickness, rib spacing, and overall depth.

4.6.12 ASEND

Puts strength/weight ratio or weight function in ascending order from minimum to maximum also saving the subscript.

4.6.13 PARAM

Calculates skin thickness (TS), rib thickness (TWS), rib spacing (BS), and checks minimum gage. Use for both 45-degree and 90-degree waffle.

4.6.14 RIBPRA

Calculates skin thickness (TS), rib thickness (TWS) and checks minimum gage for 45-degree and 90-degree waffle rib spacing option.

4.6.15 DESEND

Puts strength/weight ratio in order from maximum to minimum. Also saves the subscript.

4.6.16 WATT

Output routine for 45-degree and 90-degree waffle rib spacing option. Calculates and prints (1) fillet head radius, (2) cutting head radius, (3) weight of each sheet, and (4) total weight of section. Prints (1) skin and web thickness, (2) rib spacing, and (3) overall depth.

Table 4-2

Nomenclature for 45-Degree Waffle

FORTRAN Symbol	Engineer Symbol	Description
CC1	C1	Ratio of skin thickness to overall depth
CC2	C2	Ratio of rib thickness to over-all depth
CC3	C3	Ratio of rib spacing to overall depth
H	H	Depth
SEA	C	Correction factor
TS	t_s	Skin thickness
TWS	tw_s	Web thickness
BS	b_s	Rib spacing
RBAR	R	Equivalent radius
NXWAF	N_x	Maximum compressive loading
DIFLOD	$+N_x + N_y$	Maximum algebraic difference
VONMIS	$\sqrt{N_x^2 - N_xN_y + N_y^2}$	Maximum von Mises loading
AXX	A_x	Longitudinal extensional stiff-ness parameter
NEGDIF	$-N_x + N_y$	Maximum negative algebraic difference
NEGNX	$-N_x$	Compressive loading for maxi-mum negative algebraic difference
NEGNY	$-N_y$	Hoop loading for negative algebraic difference
NYWAF	N_y	Hoop loading corresponding to maximum N_x
GG	$g(C_1, C_2, C_3)$	Weight function
C4	C4	Ratio of fillet radius to overall depth

Table 4-2

Nomenclature for 45-Degree Waffle (Cont.)

FORTRAN Symbol	Engineer Symbol	Description
C5	C5	Ratio of cutting head radius to overall depth
HMAX	H_{max}	Maximum allowable depth
HMIN	H_{min}	Minimum allowable depth
SHEETL	Sheet	Sheet length
VIP4	-	Signal for options
CHKNX	$2C/R[f(C_1, C_2, C_3)] EH^2$	General instability
SIGY	σ_{yld}	Yield strength of material
SIGULT	σ_{ult}	Ultimate strength of material
E	E	Modulus of elasticity of material
WAFWAT	w	Weight per surface area
RN	R_n	Radius of rib intersection
RWS	R_{ws}	Fillet radius
SCR	S_{cr}	Allowable panel axial buckling stress
FSCR	F_{scr}	Allowable panel shear buckling stress
SR	SR	Panel tensile stress
FSR	F_s^r	Panel shear stress
S	S	Rib tensile stress
SRC	S_{rc}	Allowable rib axial buckling stress
DEN	ρ	Density of waffle material
MUE	μ	Poisson's ratio of material
SFULT	$S.F._{ult}$	Ultimate safety factor
SFYLD	$S.F._{yld}$	Yield safety factor

Table 4-2

Nomenclature for 45-Degree Waffle (Cont.)

FORTRAN Symbol	Engineer Symbol	Description
TMIN	TMIN	Minimum gage thickness
TRIB	TRIB	Minimum rib thickness
IZIGN	-	Signal when parameters are set to minimum
IZIGNI	-	Signal indicating waffle 45- or 90- degree analysis
CC6	C6	Ratio of skin thickness to rib spacing
CC7	C7	Ratio of rib thickness to rib spacing
CC8	C8	Ratio of overall depth to rib spacing
RATIO	$\frac{[f(C_1, C_2, C_3)]^{\frac{1}{2}}}{g(C_1, C_2, C_3)}$	Strength/weight ratio
STREN	$[f(C_1, C_2, C_3)]$	Strength function
GC123	$g(C_1, C_2, C_3)$	Weight function

4.7 ITERATION ROUTINES

The 45-degree and 90-degree waffle require an iteration approach for evaluating one or more of the variables. In C3(C8) iteration, C1(C6) and C2(C7) remain constant while C3 is changed.

C3NU, C3NEW, C8NU, and C8NEW are iteration routines based upon the following procedure. The purpose of the iteration routine is to zero in on the optimum design by reducing or increasing (C3 or C8) in increments of 1.0, 0.1, and 0.01 until the conditions (general instability, rib crippling, and panel buckling) are all satisfied. When this occurs we have the best design, that is, optimization of design. Then, return to main program and calculate weight.

4.8 ERROR RETURNS

4.8.1 W45MAS

If program is unable to find an optimum design the user should increase restrictions of HMAX.

4.8.2 W90MAS

If program is unable to find an optimum design the user should increase restrictions of HMAX.

4.8.3 H-OPTION-45

If program is unable to find an optimum design the user should increase restrictions of HMAX.

4.8.4 H-OPTION-90

If program is unable to find an optimum design the user should increase restrictions of HMAX.

4.8.5 45-DEGREE RIB SPACING

Investigate a more reasonable value. Option - GRINGO of rib spacing (BS).

4.8.6 90-DEGREE RIB SPACING

Investigate a more reasonable value. Option - RIBOPT.

4.9 90-DEGREE WAFFLE

4.9.1 90-DEGREE WAFFLE STIFFENED SUBROUTINE

The function of this subroutine is to design an optimum cylindrical or conical structure with strength and buckling as governing criteria. Conical sections are analyzed by treating them as a cylinder of equivalent length and radius. The program will determine the following optimum design parameters:

a. Skin thickness (TS).
b. Rib thickness (TWS).
c. Rib spacing (BS).
d. The overall depth (H).

4.9.2 PROGRAM DESCRIPTION

The strength/weight ratio as a function of C1, C2, and C3 (see Table 4-3) is analyzed and the maximum ratio is checked to see if all conditions are satisfied. These conditions include general instability, local panel buckling, rib crippling, rib spacing, and HMAX. If it is determined that this is the optimum design a return to main program is made to check for type of case. If design is not optimum the next largest value is checked and the process is repeated until no condition is violated.

The program then checks for a buckling or strength governed case. If it is a buckling governed case the following steps are used:

a. Design parameters are calculated.
b. Check for minimum gage. If satisfactory, calculate weight.
c. If minimum gage is set the iteration scheme is used to increase C3 so we have same buckling strength.

It it is a strength governed case proceed as follows:

a. Increase depth (H).
b. Check if H is greater than HMAX.
c. Calculate design parameters.
d. Check for minimum gage. If satisfactory calculate weight.
e. If minimum gage is set the iteration scheme is used to increase C3 to have equal strength.
f. Check general instability, panel buckling, rib crippling. If all are satisfied, calculate design parameters and total weight and exit the program.
g. If not decrease C3 for rib spacing, calculate design parameters and total weight and exit.

The 90-degree stiffened waffle subroutine is also provided with the option to specify the overall depth or the rib spacing. Given one of these options the other three design parameters are chosen such that any optimum design results. Basically the same procedure is used as previously described with the exception that the optimization is performed with three parameters rather than four.

Table 4-3

Parameters Built Into Program 90-Degree Waffle

1. General Waffle 90-Degree Procedure					
C1	0.05	0.06	0.07	0.08	0.09
C2	0.02	0.04	0.06	0.08	0.10
C3	3.0	4.0	5.0	6.0	7.0
2. Depth Option (H)					
C1	0.05	0.06	0.07	0.08	0.09
C2	3.0	4.0	5.0	6.0	7.0
3. Rib Spacing Option (BS)					
C6	0.00716	0.01287	0.01858	0.02429	0.030
C7	0.00286	0.010395	0.01793	0.025465	0.033

4.9.3 SUMMARY OF SUBROUTINES FOR 90-DEGREE WAFFLE

4.9.3.1 W90MAS

Main subroutine to establish a method for optimizing 90-degree waffle for each section (is divided into sheets). The analysis is done for strength- and buckling-governed cases.

4.9.3.2 RAT9

Computes strength/weight ratio based on C1, C2, C3 that are built into program.

4.9.3.3 PANEL

Calculates allowable panel buckling due to compressive and tension panel buckling is checked for maximum compressive N_x and maximum negative algebraic value.

4.9.3.4 C3NU

Reduces the value of C3 in increments of 1.0m 0.1, and 0.01 until general instability, panel buckling, and web crippling are satisfied for 90-degree waffle.

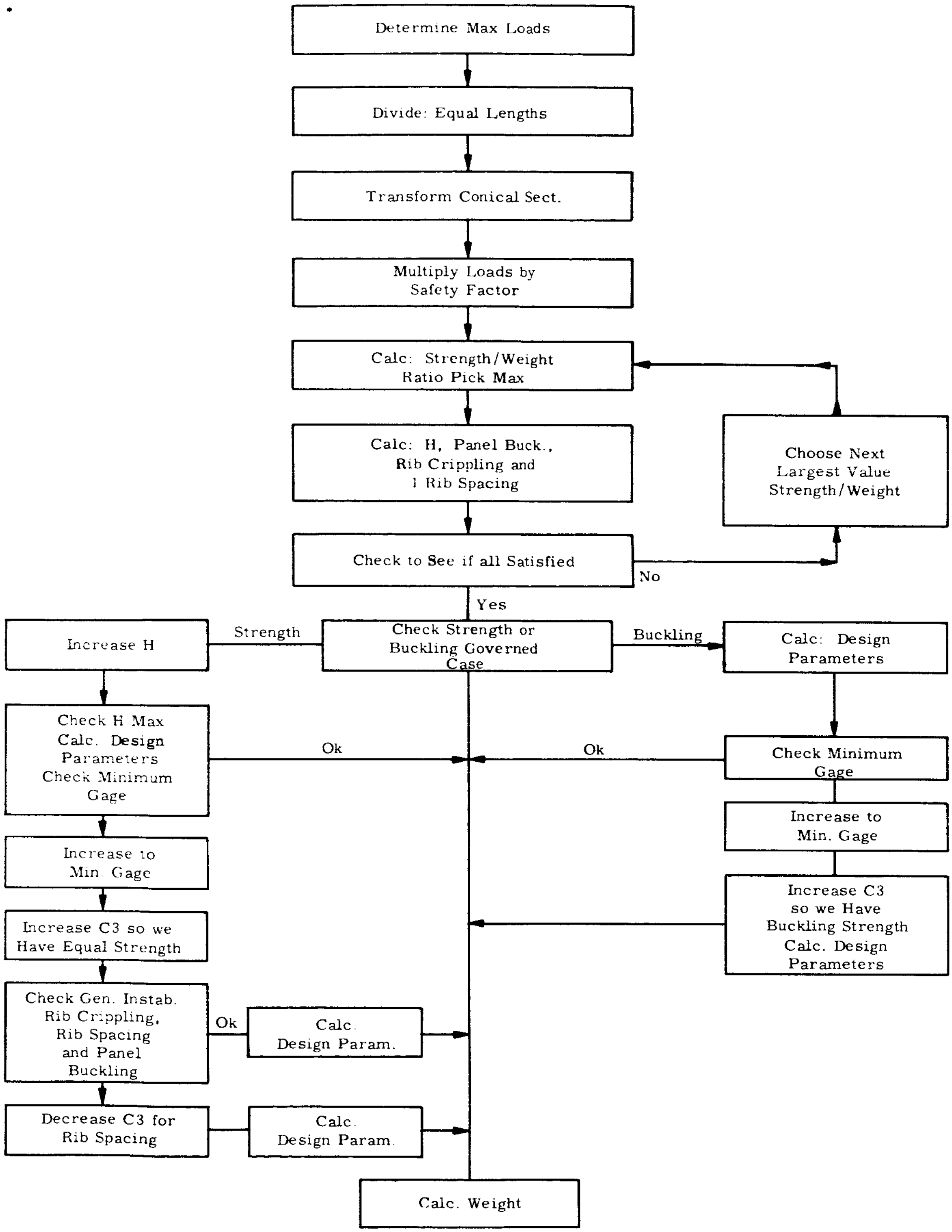


Figure 4-36. General Flow Chart for 90-Degree Waffle Stiffened Subprogram

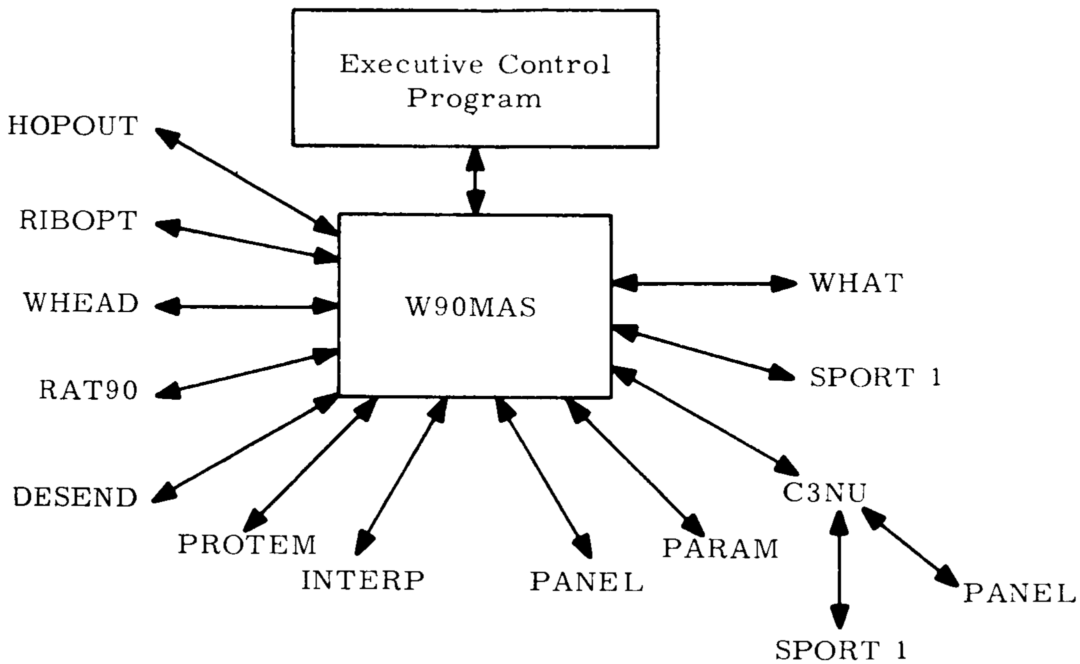


Figure 4-37. W90MAS

D I M E N S I O N E D   V A R I A B L E S

SYMBOL	STORAGES	SYMBOL	STORAGES	SYMBOL	STORAGES	SYMBOL	STORAGES	SYMBOL	STORAGES
NC	200	ISTEP	125,1	STEP	125,1	LIMIT	10,15	QUEEN	10,10

Figure 4-38. W90MAS Flow Chart (Sheet 1 of 7)

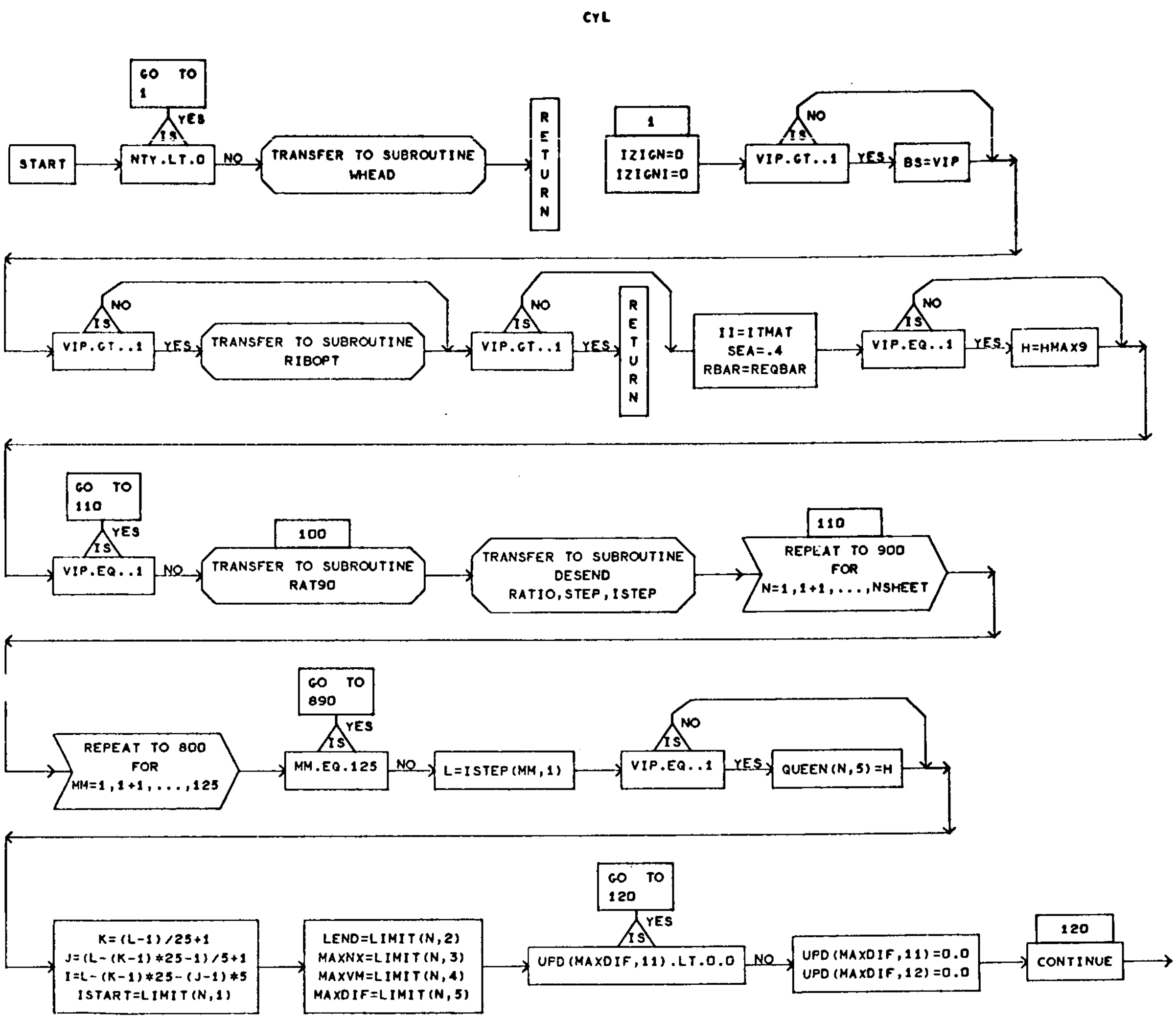


Figure 4-38. W90MAS Flow Chart (Sheet 2 of 7)

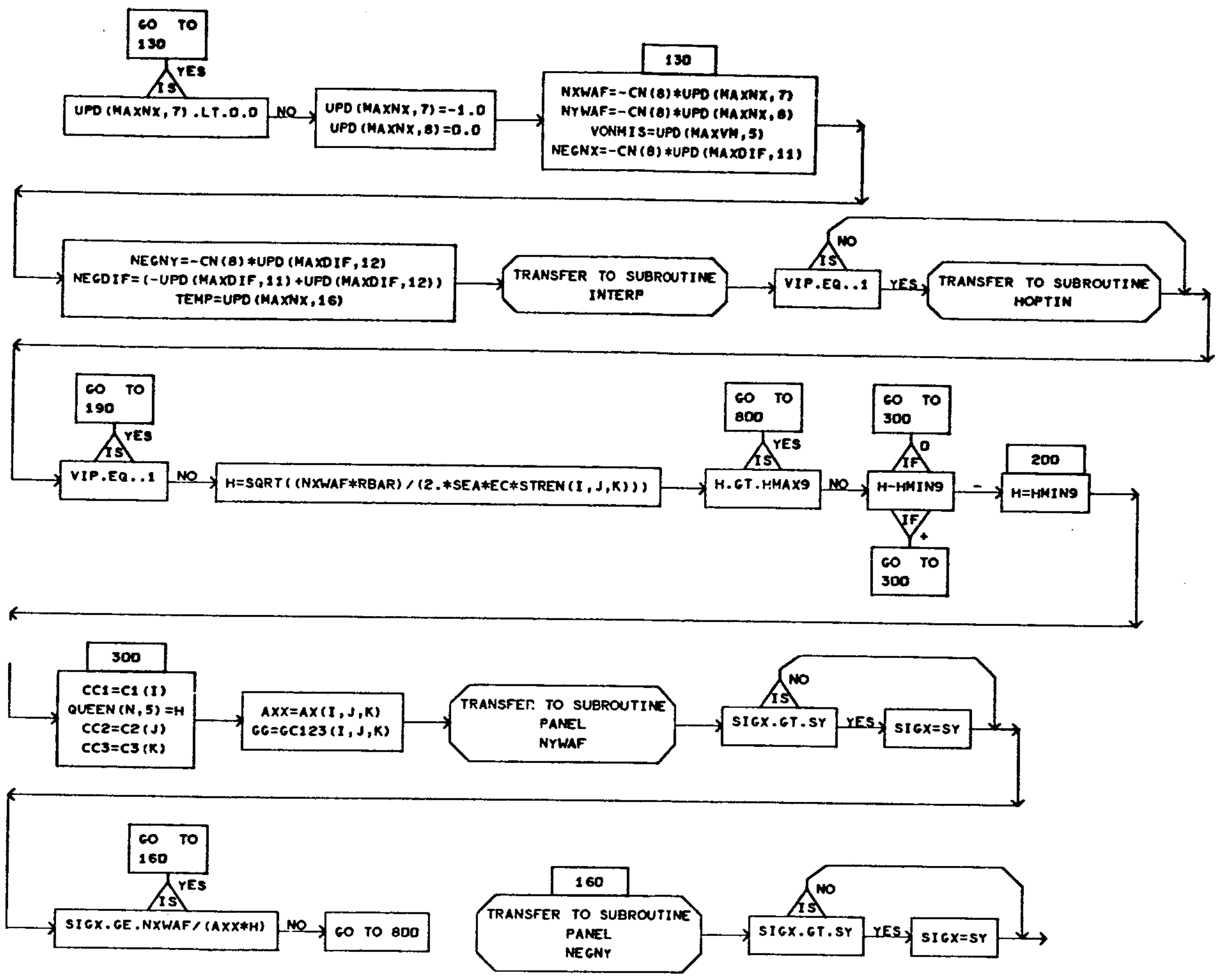


Figure 4-38. W90MAS Flow Chart (Sheet 3 of 7)

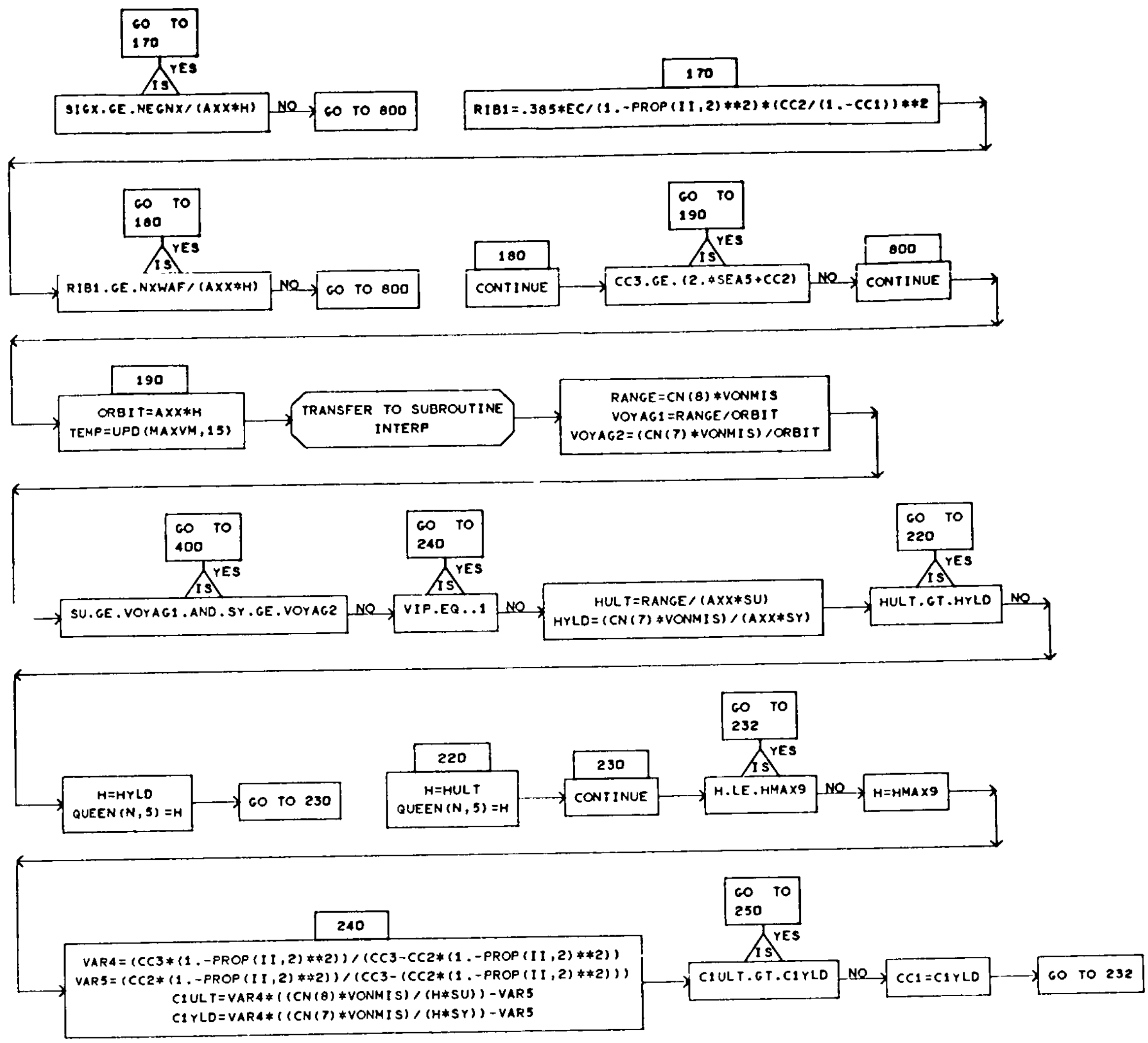


Figure 4-38. W90MAS Flow Chart (Sheet 4 of 7)

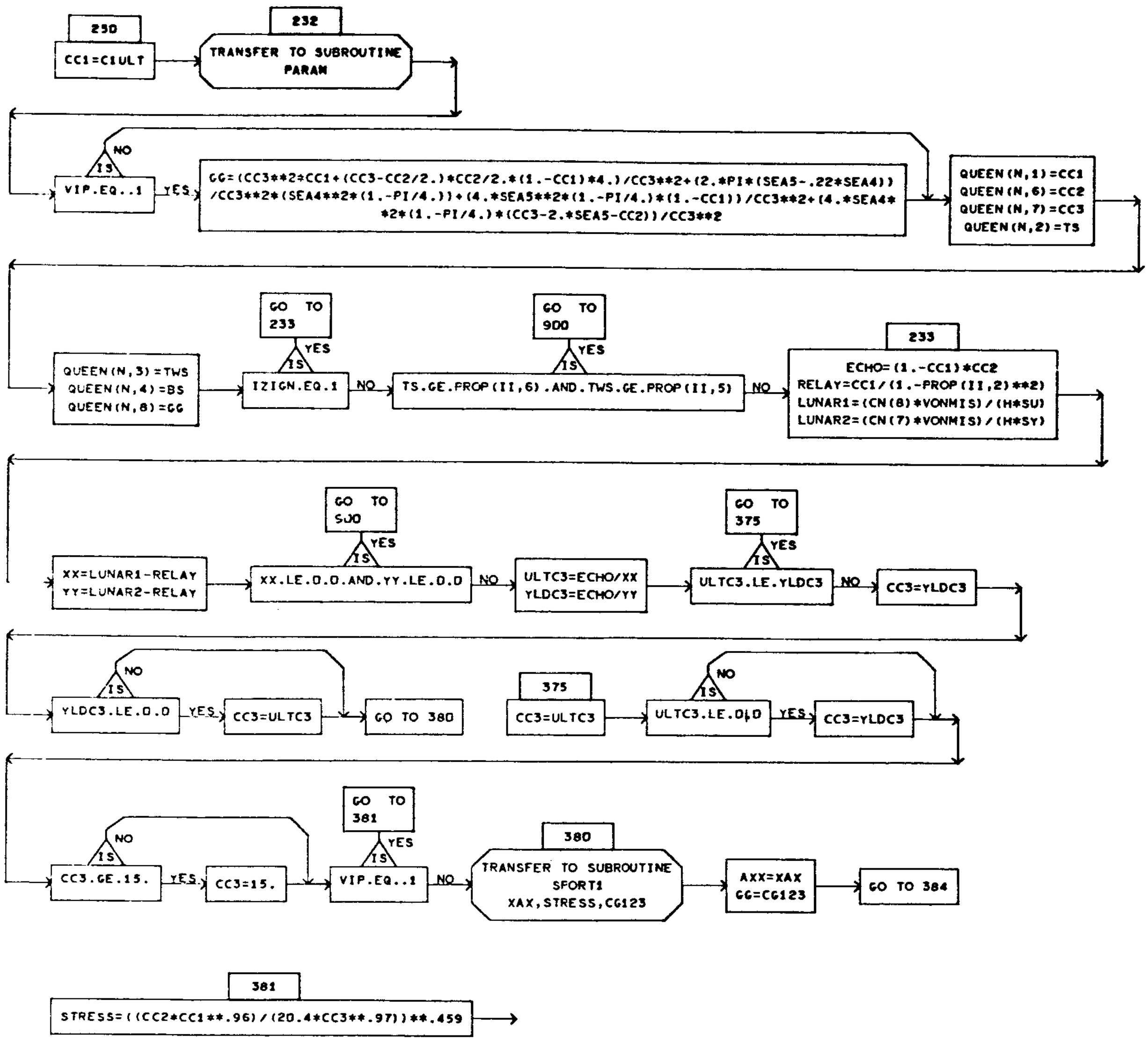


Figure 4-38. W90MAS Flow Chart (Sheet 5 of 7)

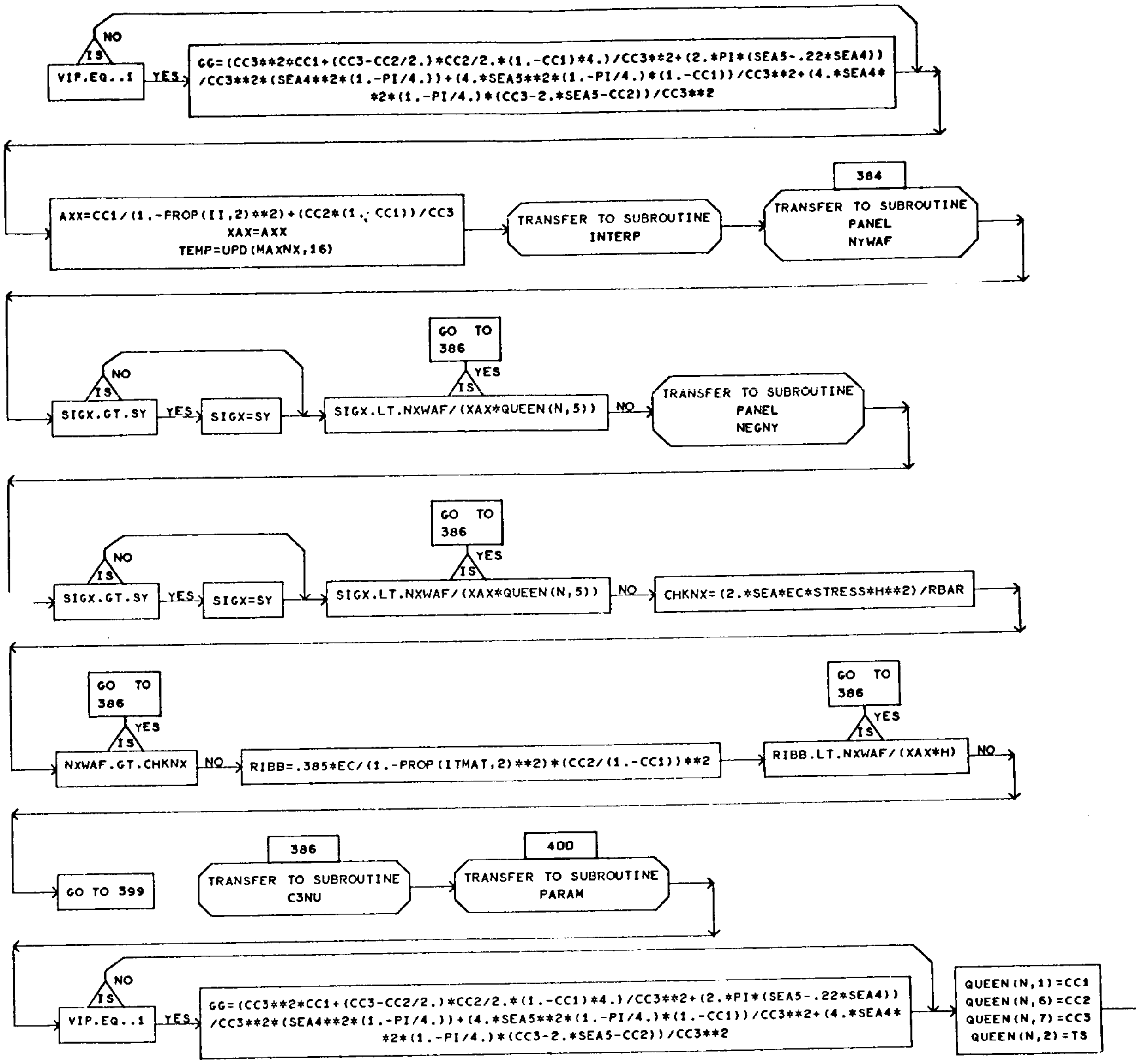


Figure 4-38. W90MAS Flow Chart (Sheet 6 of 7)

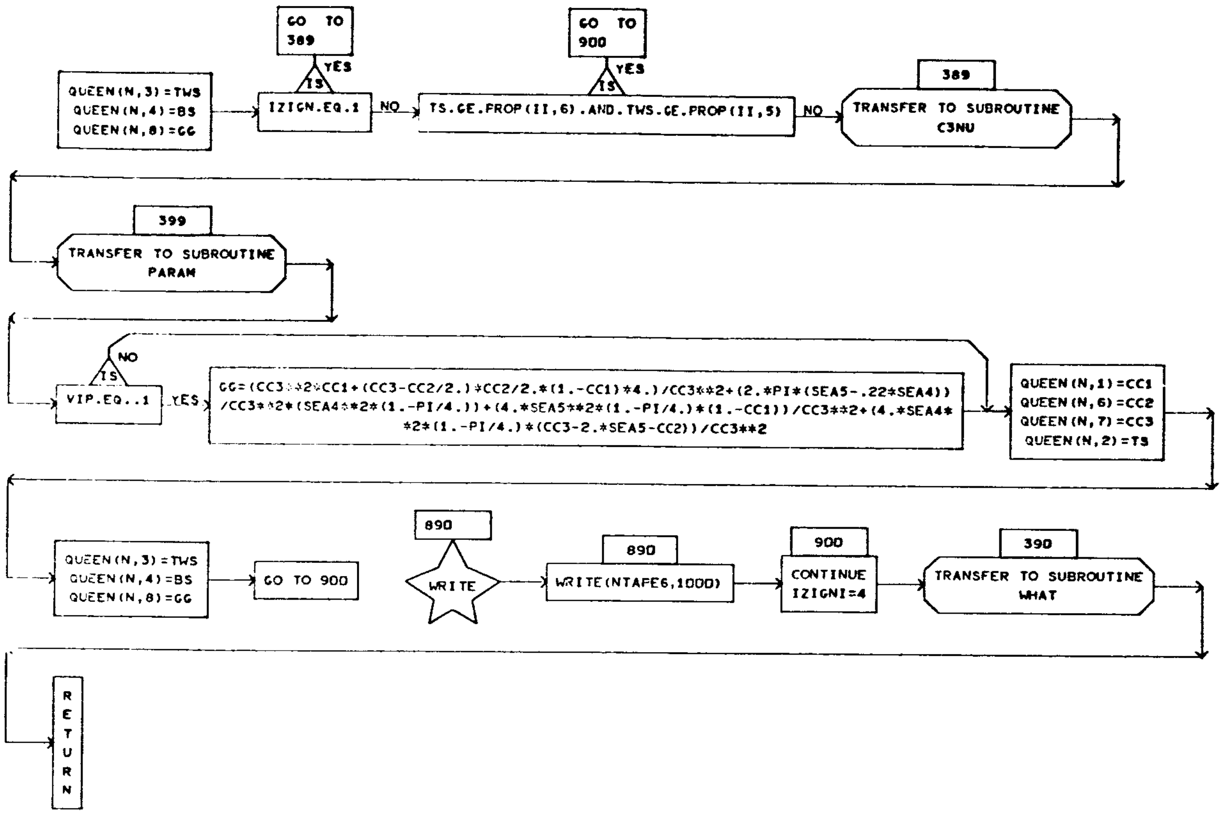


Figure 4-38. W90MAS Flow Chart (Sheet 7 of 7)

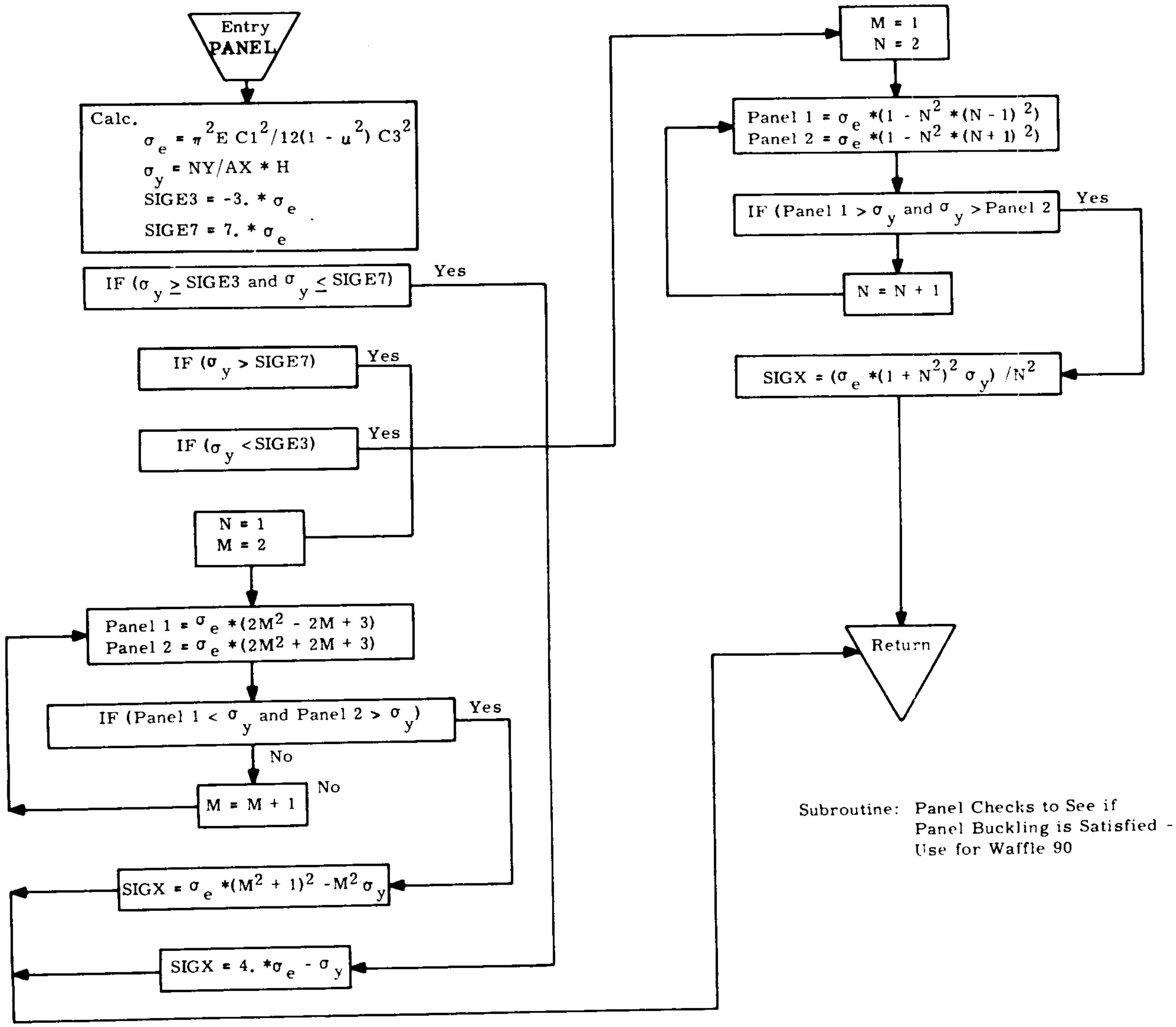


Figure 4-39.. PANEL Subroutine Flow Chart

D I M E N S I O N E D   V A R I A B L E S

SYMBOL	STORAGES	SYMBOL	STORAGES	SYMBOL	STORAGES	SYMBOL	STORAGES	SYMBOL	STORAGES
NC	200	LIMIT	10,15	QUEEN	10,10				

Figure 4-40. HOPOUT Subroutine Flow Chart (Sheet 1 of 10)

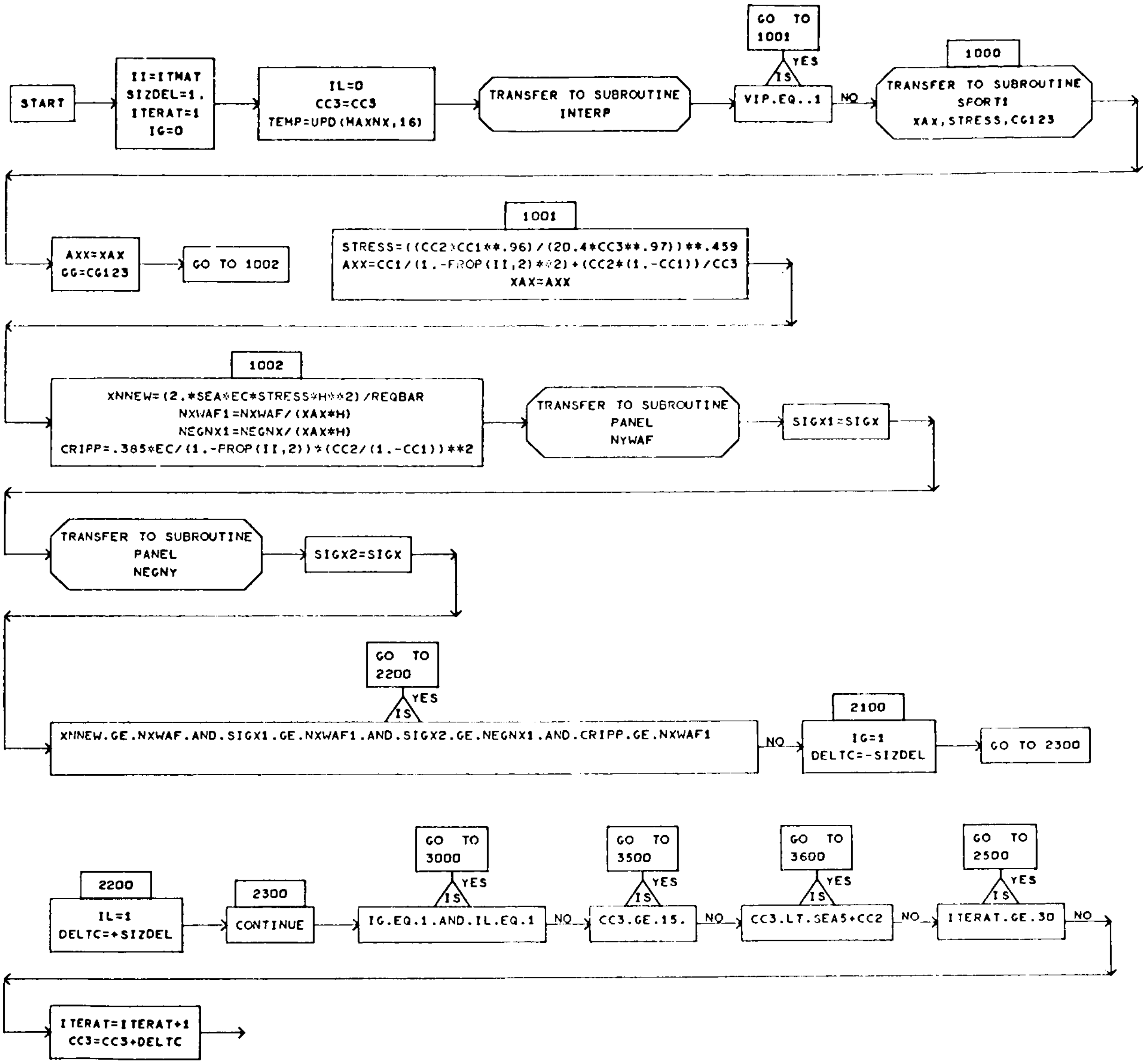


Figure 4-40. HOPOUT Subroutine Flow Chart (Sheet 2 of 10)

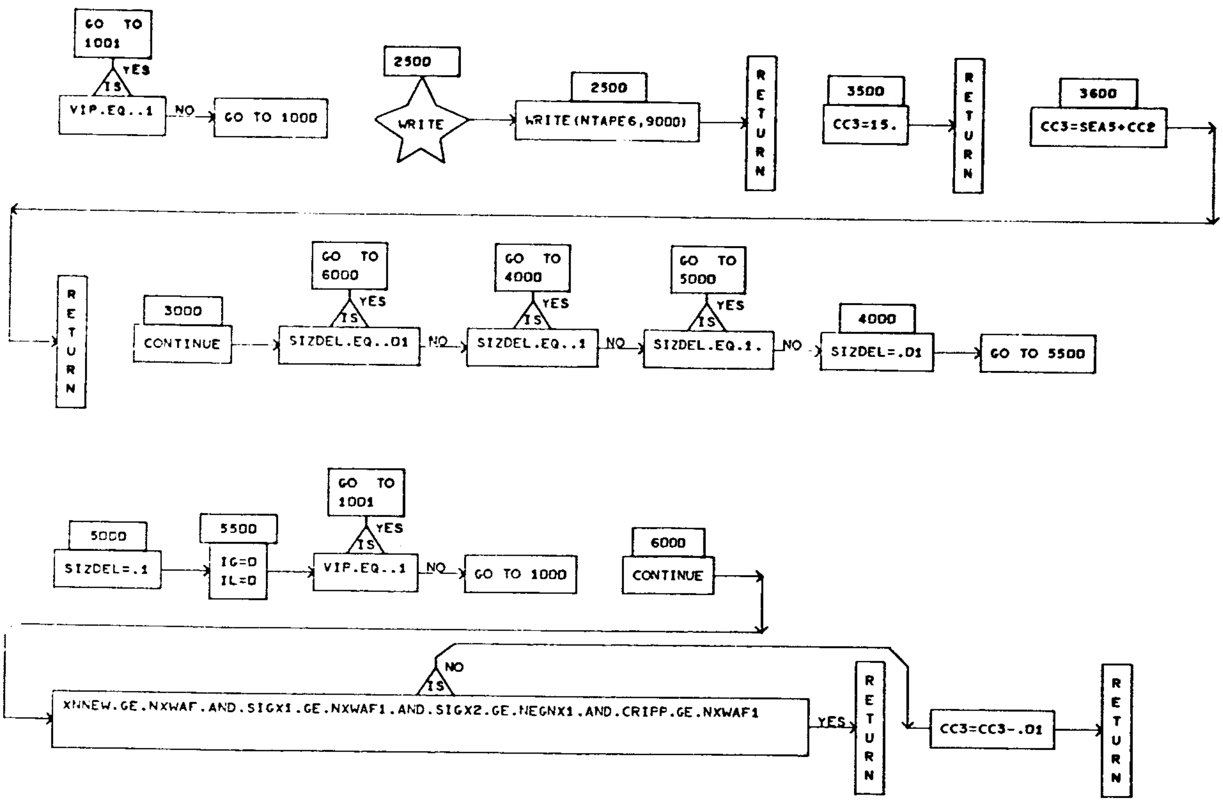


Figure 4-40. HOPOUT Subroutine Flow Chart (Sheet 3 of 10)

DIMENSIONED VARIABLES

SYMBOL	STORAGES	SYMBOL	STORAGES	SYMBOL	STORAGES	SYMBOL	STORAGES	SYMBOL	STORAGES
NC	200	LIMIT	10,15	QUEEN	10,10	STAIR	25	ISTAIR	25

Figure 4-40. HOPOUT Subroutine Flow Chart (Sheet 4 of 10)

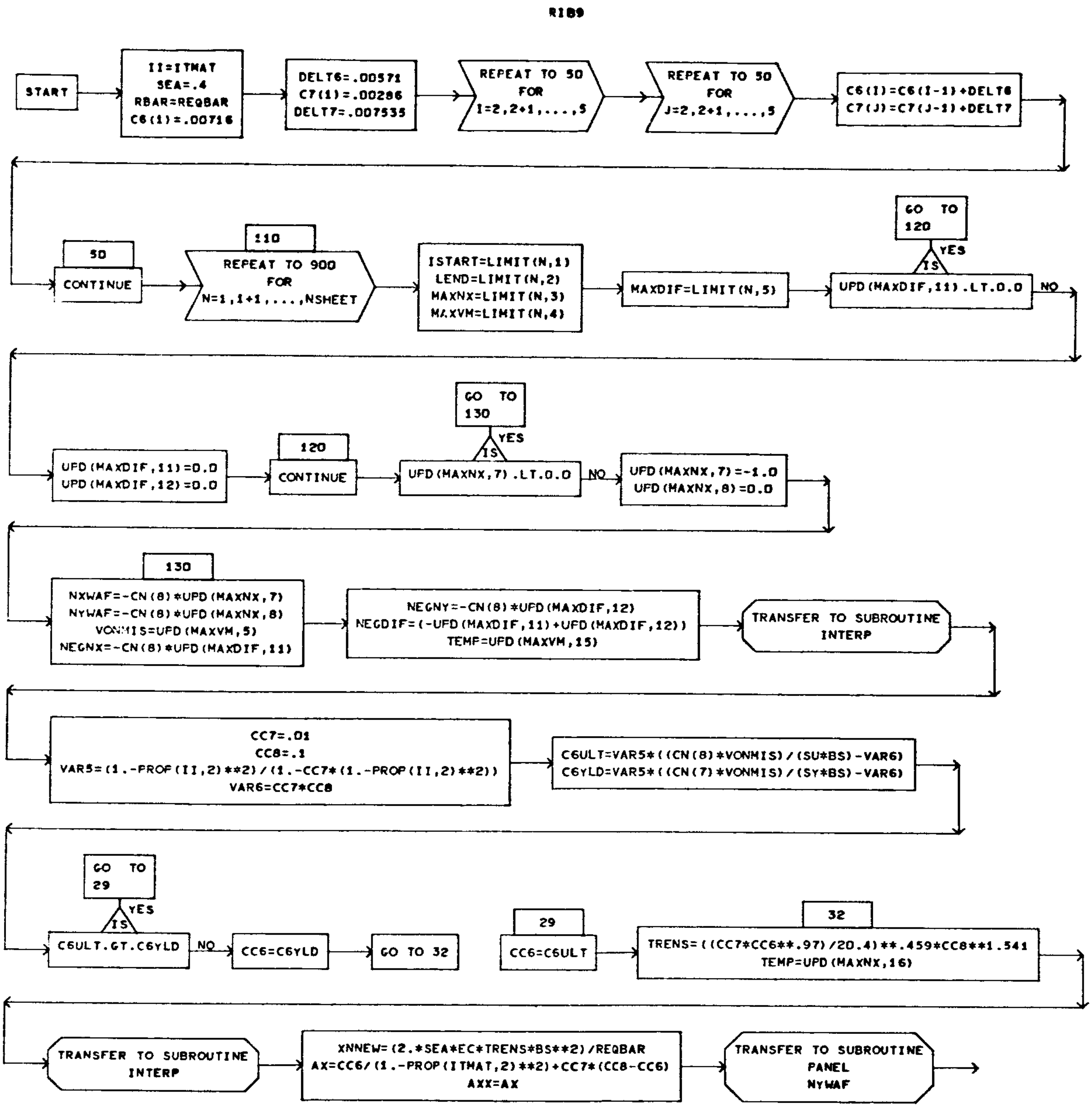


Figure 4-40. HOPOUT Subroutine Flow Chart (Sheet 5 of 10)

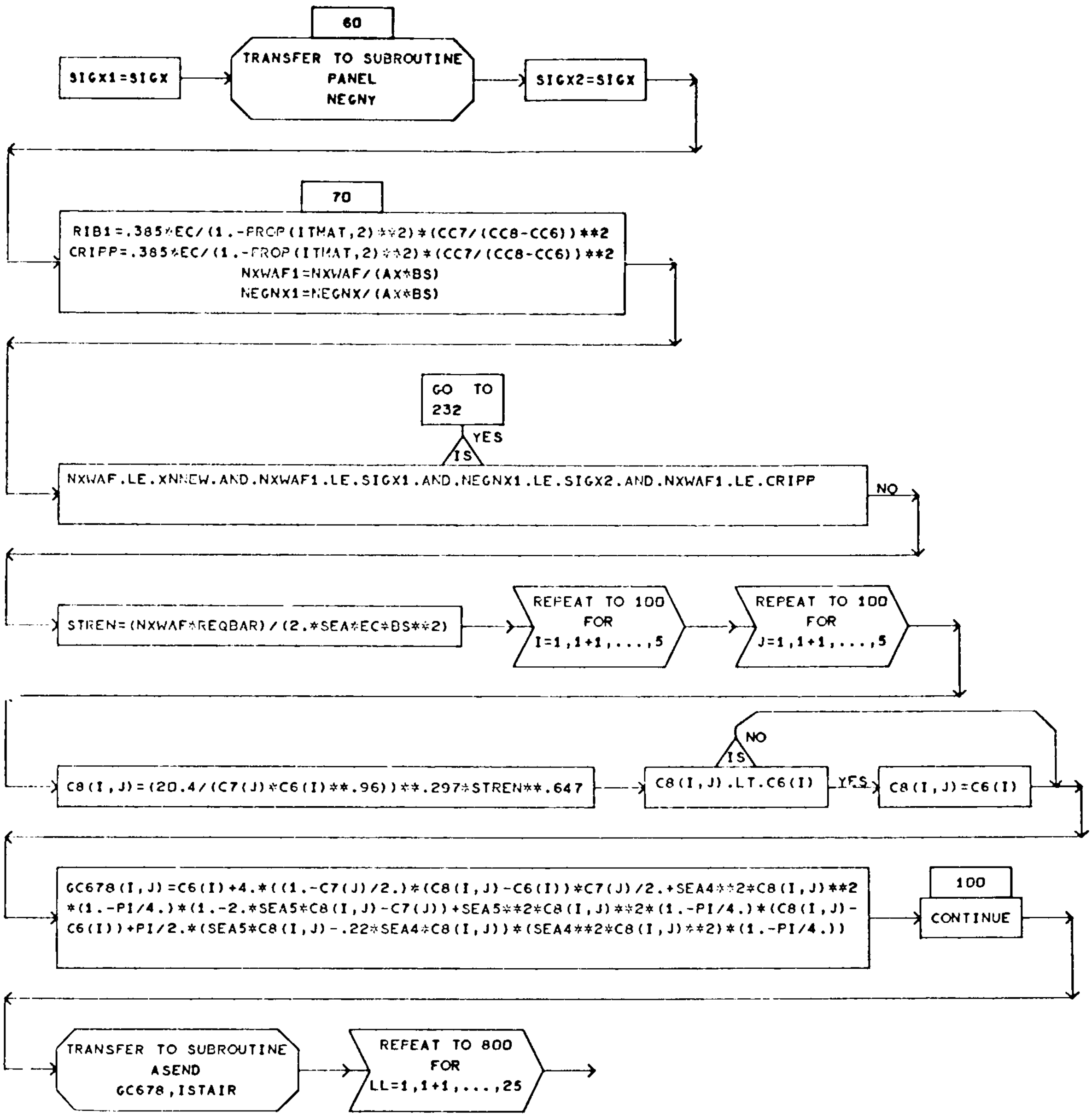


Figure 4-40. HOPOUT Subroutine Flow Chart (Sheet 6 of 10)

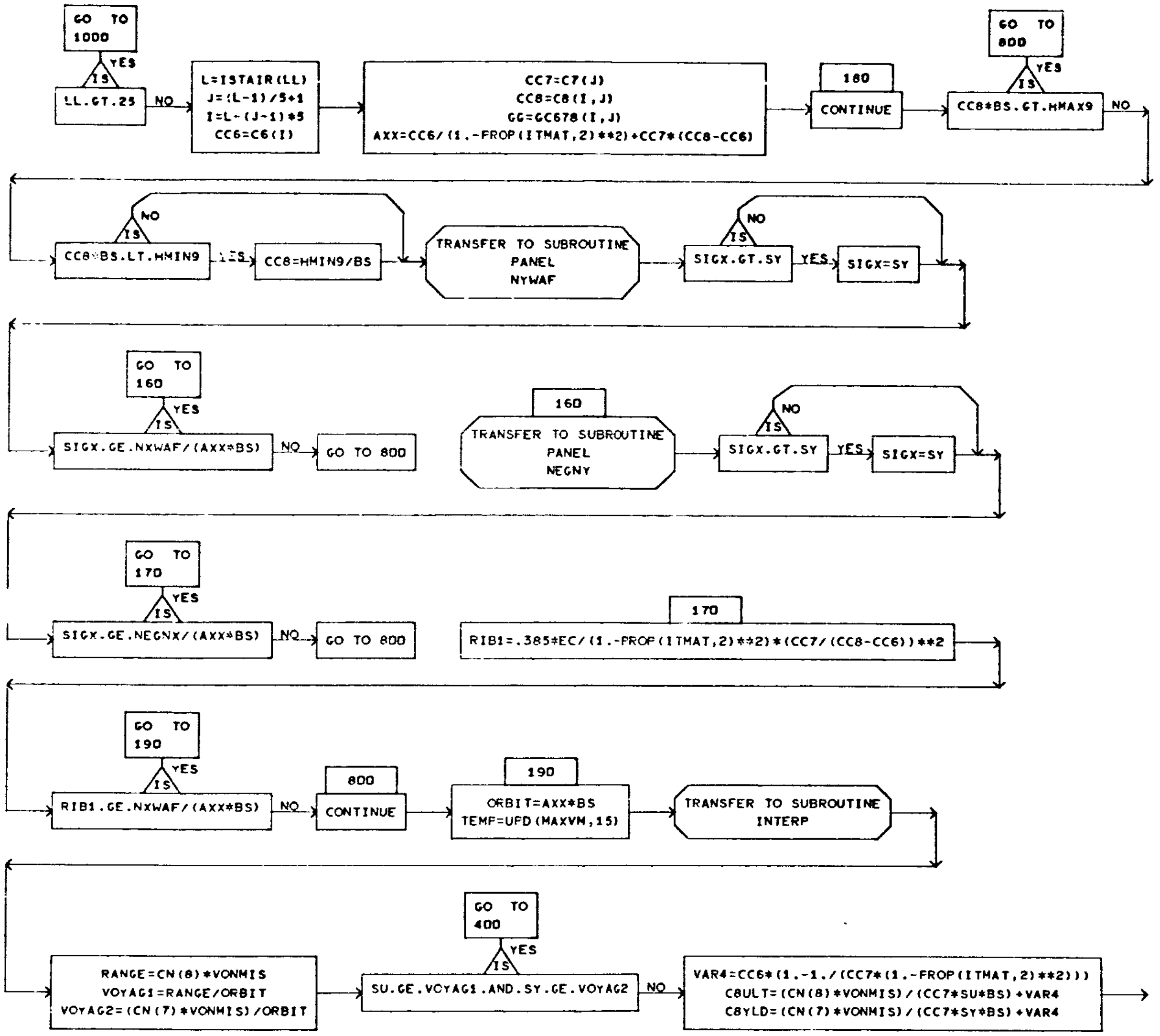


Figure 4-40. HOPOUT Subroutine Flow Chart (Sheet 7 of 10)

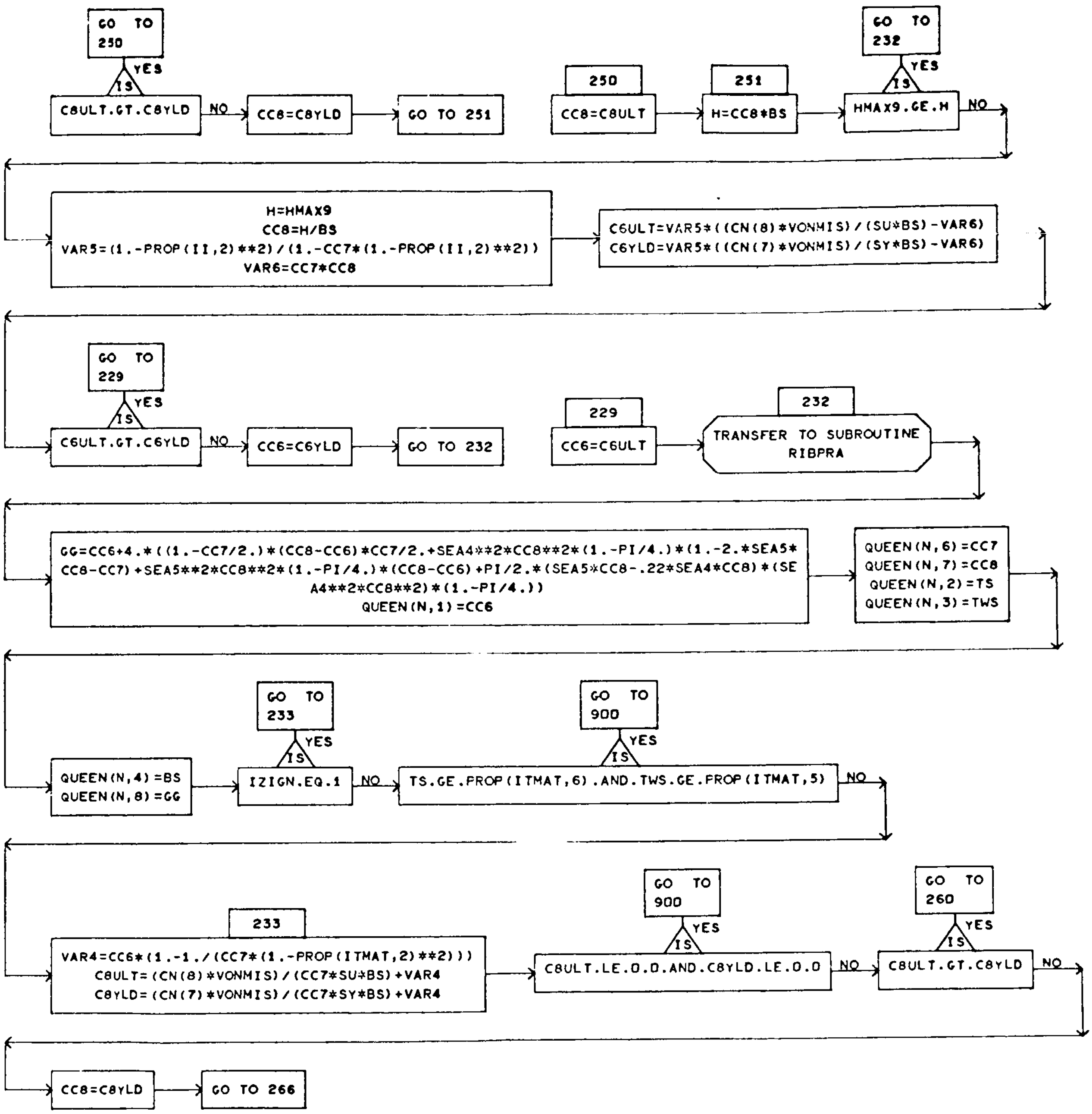


Figure 4-40. HOPOUT Subroutine Flow Chart (Sheet 8 of 10)

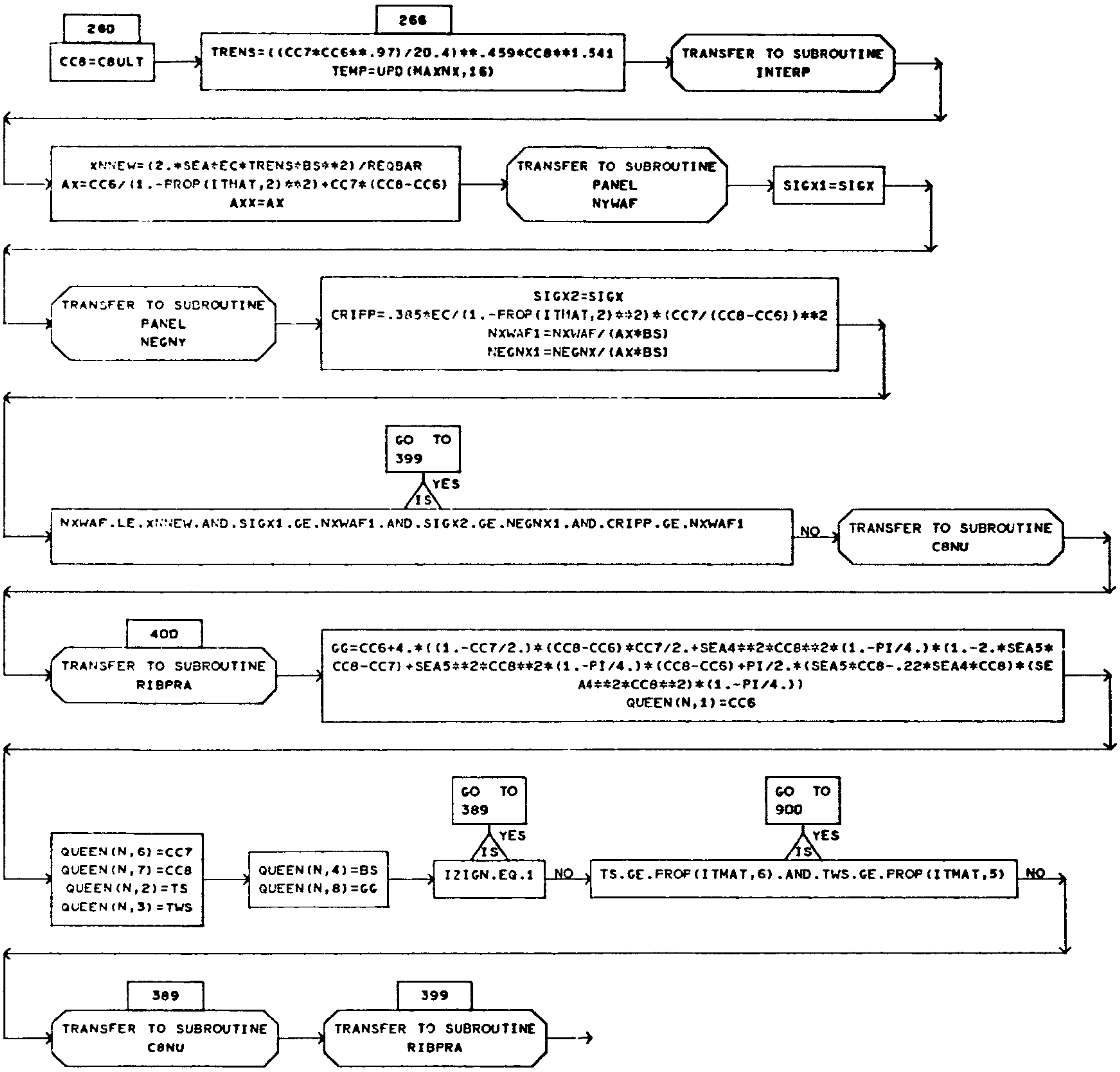


Figure 4-40. HOPOUT Subroutine Flow Chart (Sheet 9 of 10)

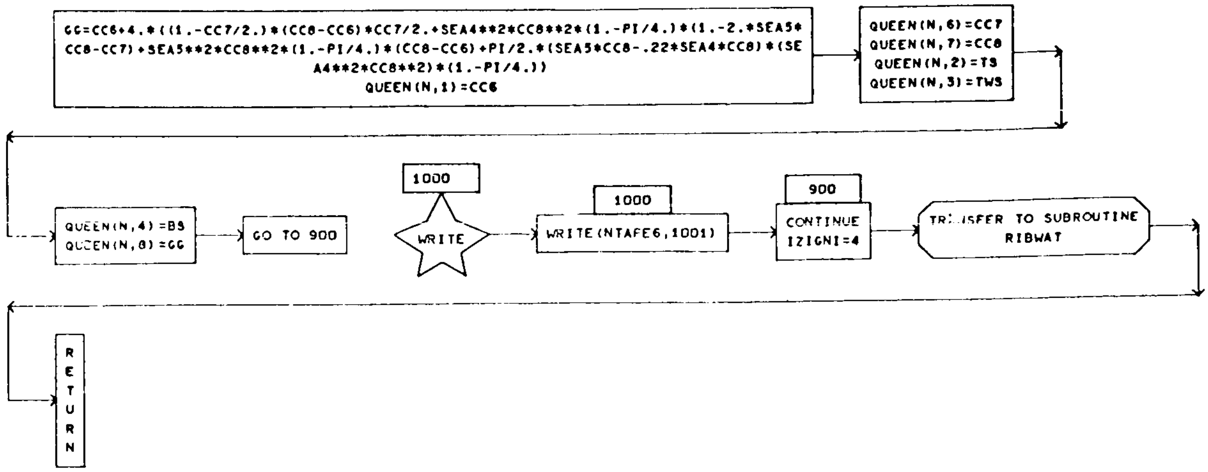


Figure 4-40. HOPOUT Subroutine Flow Chart (Sheet 10 of 10)

DIMENSIONED VARIABLES

SYMBOL	STORAGES	SYMBOL	STORAGES	SYMBOL	STORAGES	SYMBOL	STORAGES	SYMBOL	STORAGES
LIMIT	10,15	QUEEN	10,10	NC	200	STAIR	25	ISTAIR	25

Figure 4-41. HOPTIN Subroutine Flow Chart (Sheet 1 of 4)

HOPTI

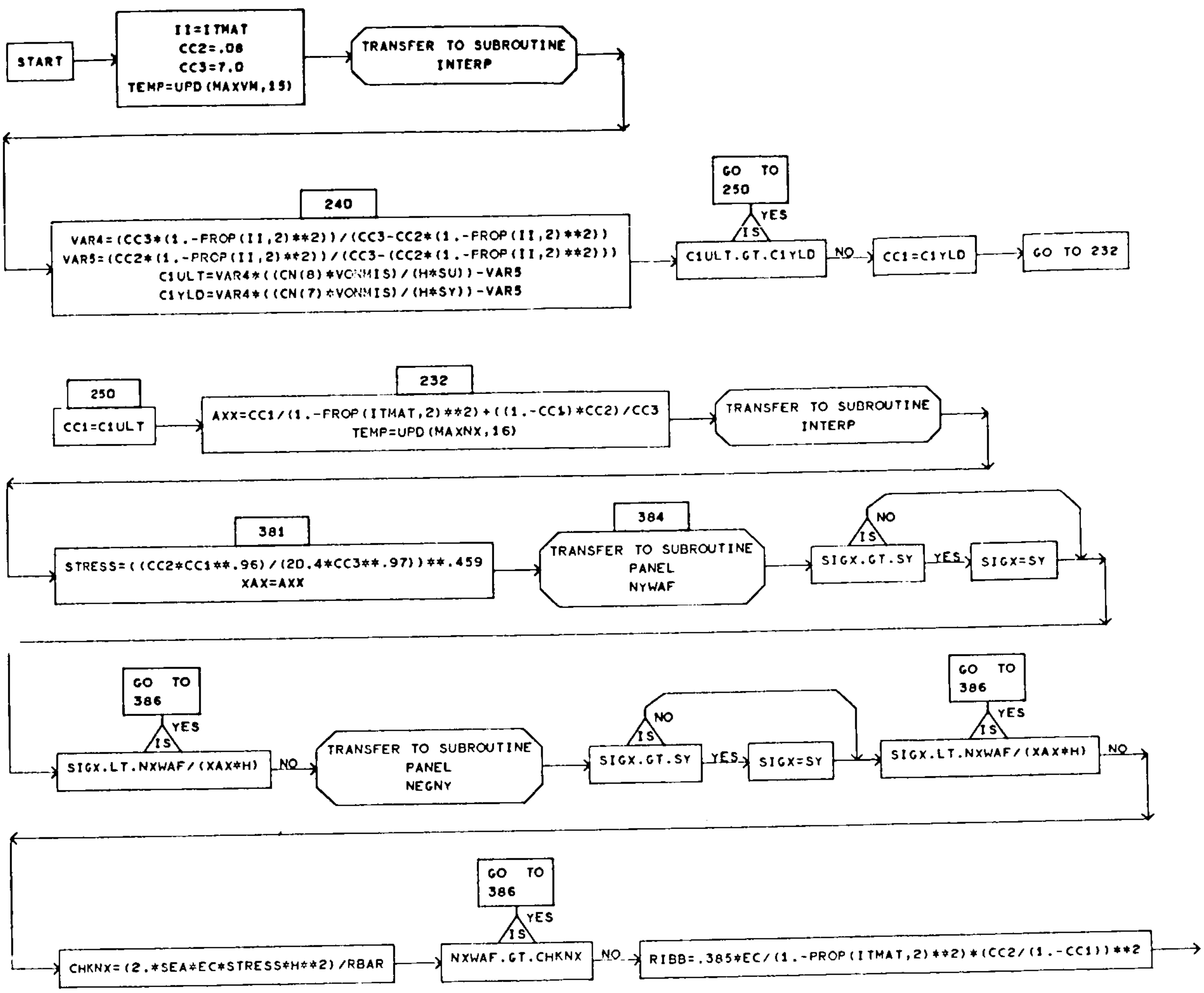


Figure 4-41. HOPTIN Subroutine Flow Chart (Sheet 2 of 4)

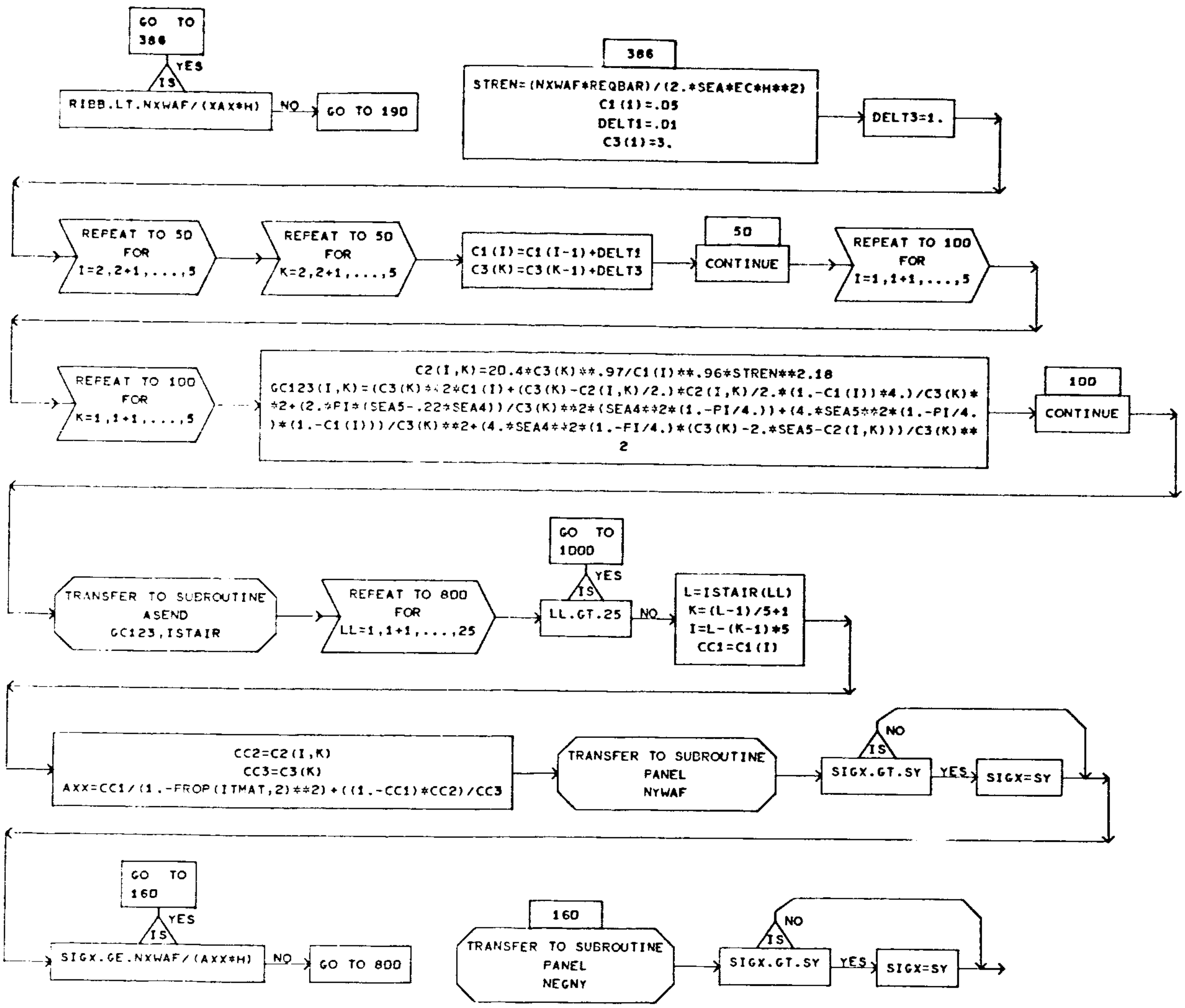


Figure 4-41. HOPTIN Subroutine Flow Chart (Sheet 3 of 4)

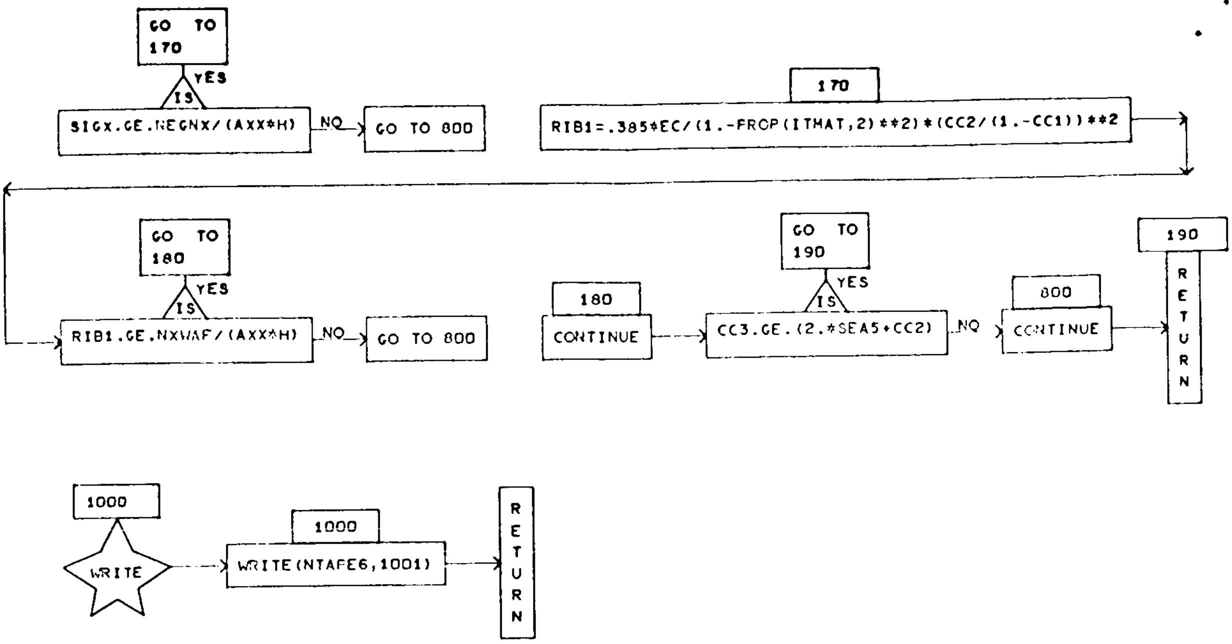


Figure 4-41. HOPTIN Subroutine Flow Chart (Sheet 4 of 4)

RAT 90 for Waffle-90

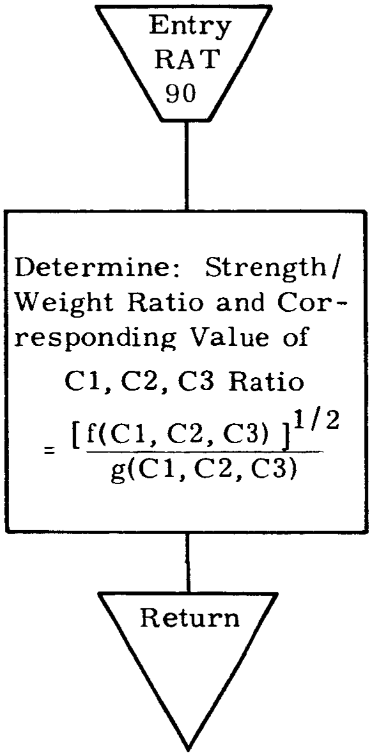


Figure 4-42. RAT90 Subroutine Flow Chart

Subroutine: Sport 1

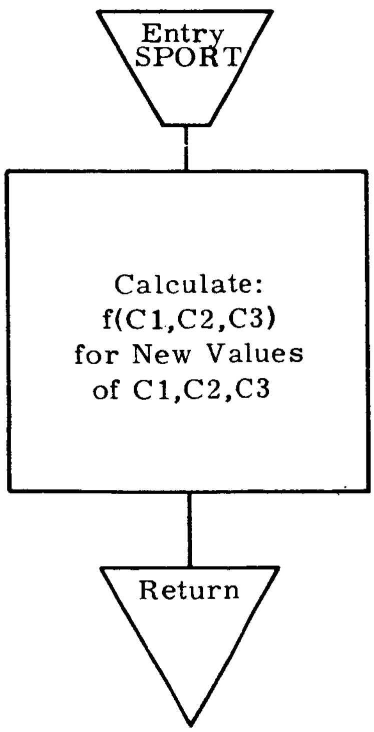


Figure 4-43. SPORT1 Subroutine Flow Chart

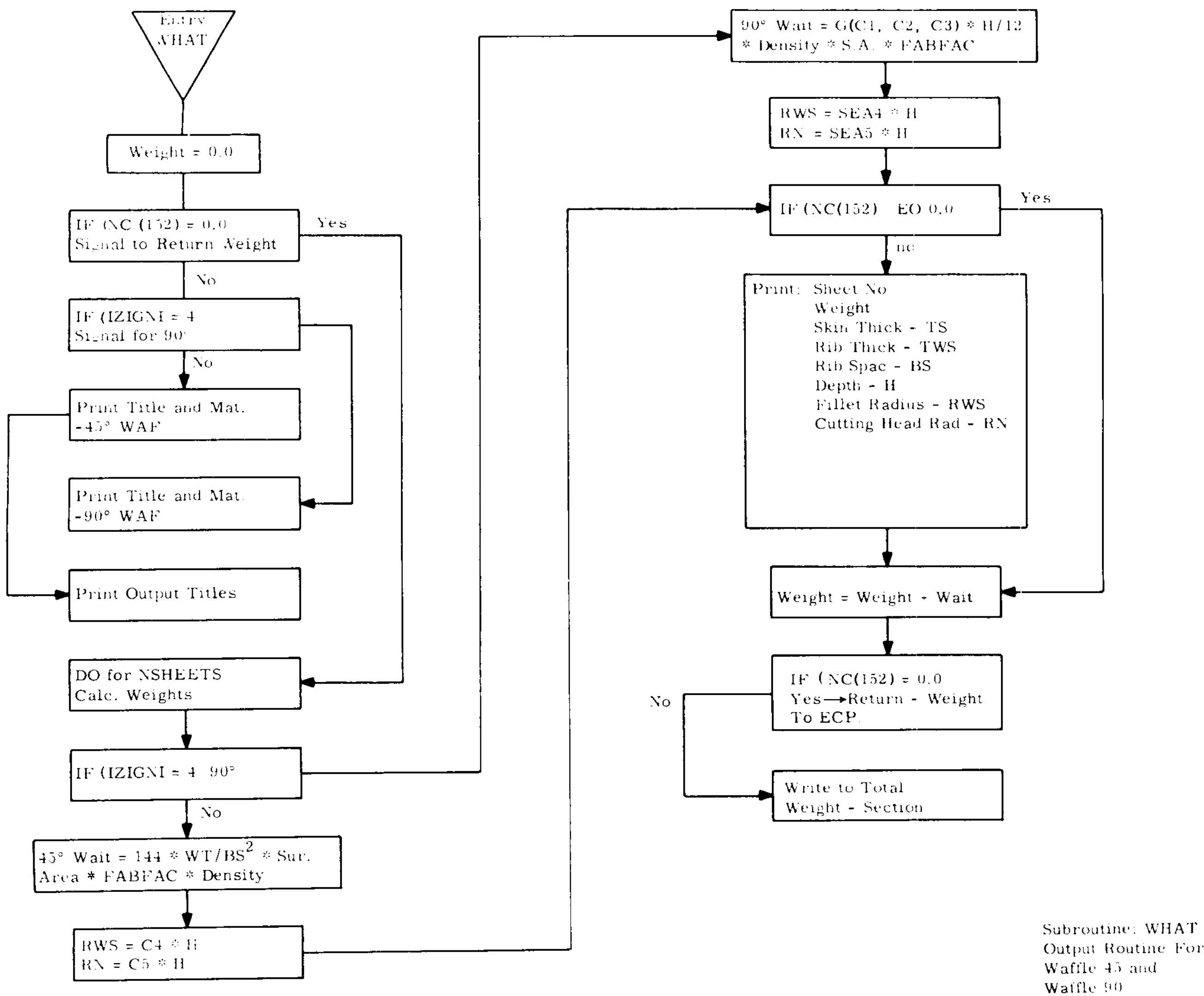


Figure 4-44. WHAT Subroutine Flow Chart

Subroutine: DESEND - use for WAF 45 and WAF 90

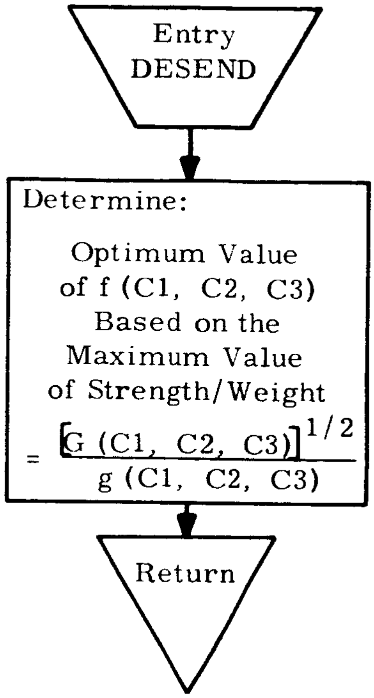


Figure 4-45. DESEND Subroutine Flow Chart

Subroutine: ASEND - use for H-Option and 35-Option on Waffle 45, Waffle 90

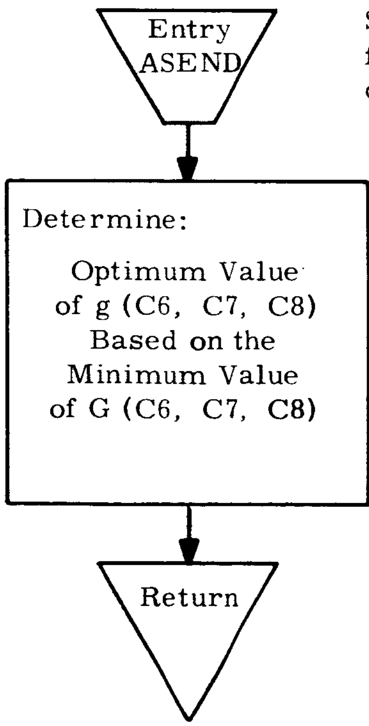


Figure 4-46. ASEND Subroutine Flow Chart

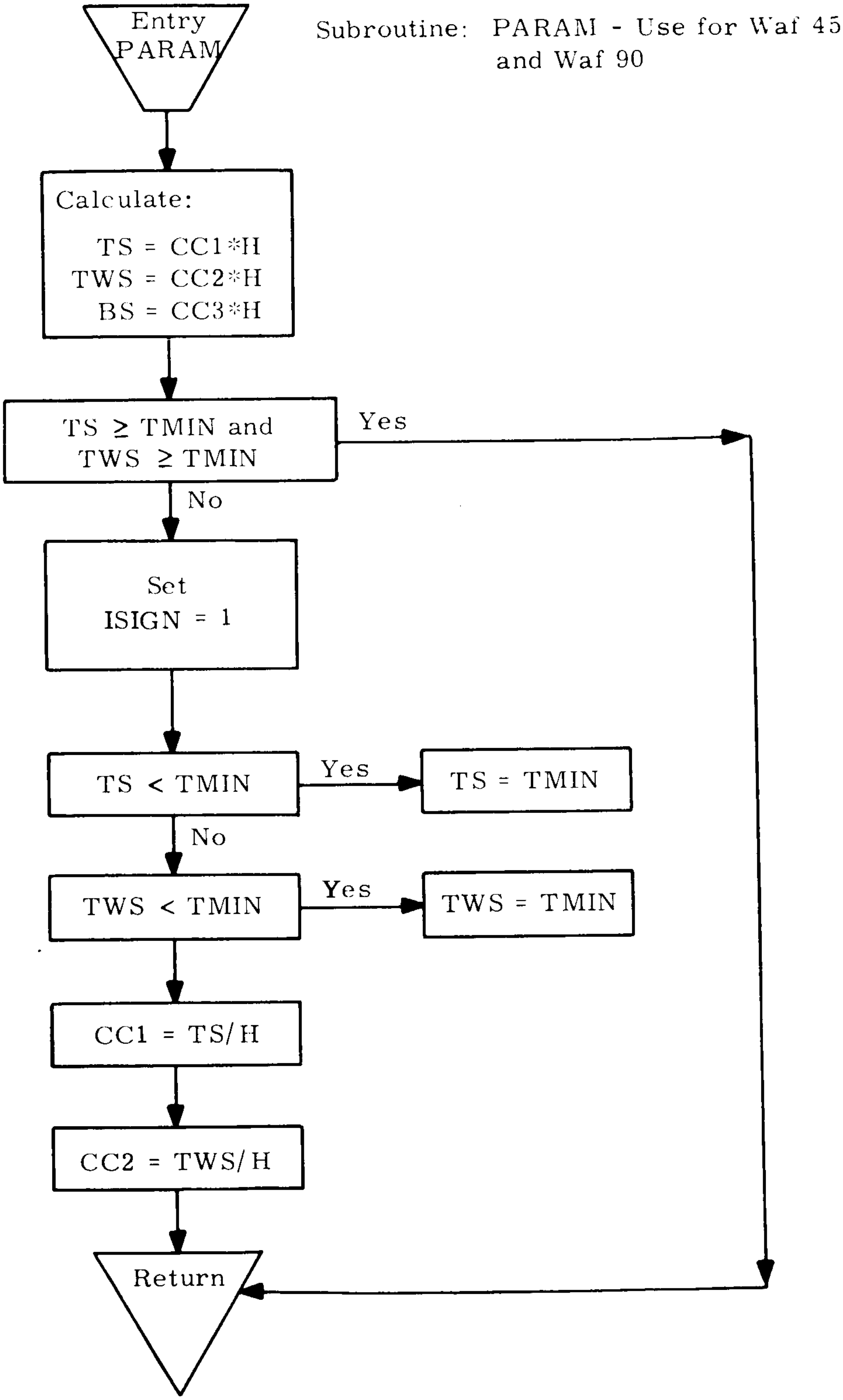


Figure 4-47. PARAM Subroutine Flow Chart

4.9.3.5 SPORT1

Recalculates strength/weight ratio based on new values of C1, C2, or C3 that were calculated in main routine for 90-degree waffle.

4.9.3.6 RIBOPT

Option to specify rib spacing for 90-degree waffle.

4.9.3.7 HOPTIN

Option to specify overall depth for 90-degree waffle.

4.9.3.8 C8NU

Reduces or increases the value of C8 in increments of 1.0, 0.1, and 0.01 until general instability, panel buckling, and web crippling are satisfied for 90-degree waffle rib spacing option.

4.9.3.9 WHAT

Output routine for both 45-degree and 90-degree waffle. Calculates and prints (1) fillet head radius and cutting head radius, (2) weight of each sheet, and (3) total weight of section. Prints skin thickness, web thickness, rib spacing, and overall depth.

4.9.3.10 ASEND

Puts strength/weight ratio or weight function in ascending order from minimum to maximum also saving the subscript.

4.9.3.11 PARAM

Calculates skin thickness (TS), rib thickness (TWS), rib spacing (BS), and checks minimum gage. Use for both 45-degree and 90-degree waffle.

4.9.3.12 RIBPRA

Calculates skin thickness (TS), rib thickness (TWS), and checks minimum gage for 45-degree and 90-degree waffle rib spacing option.

4.9.3.13 DESEND

Puts strength/weight ratio in order from maximum to minimum. Also saves the subscript.

4.9.3.14 WATT

Output routine for 45-degree and 90-degree waffle rib spacing option. Calculates and prints (1) fillet head radius, (2) cutting head radius, (3) weight of each sheet, and (4) total weight of section. Prints (1) skin and web thickness, (2) rib spacing, and (3) overall depth.

Table 4-4

Nomenclature for 90-Degree Waffle

FORTRAN Symbol	Engineer Symbol	Description
CC1	C1	Ratio of skin thickness to overall depth
CC2	C2	Ratio of rib thickness to overall depth
CC3	C3	Ratio of rib spacing to overall depth
H	H	Depth
SEA	C	Correction factor
RBAR	R	Equivalent radius
NXWAF	N_x	Maximum compressive loading
DIFLOD	$+ N_x + N_y$	Maximum algebraic difference
VONMIS	$\sqrt{N_x^2 - N_x N_y + N_y^2}$	Maximum von Mises loading
AXX	A_x	Longitudinal extensional stiffness parameter
NEGDIF	$- N_x + N_y$	Maximum negative algebraic difference
NEGNX	$- N_x$	Compressive loading for maximum negative algebraic difference
NEGNY	N_y	Hoop loading for negative algebraic difference
NYWAF	N_y	Hoop loading corresponding to maximum N_x
IZIGN	-	Signal when parameters are set to minimum

Table 4-4

Nomenclature of 90-Degree Waffle (Cont.)

FORTRAN Symbol	Engineer Symbol	Description
IZIGNI	-	Signal indicating 45- or 90-degree analysis
VIP	-	Signal for options
SIGX	σ_x	Allowable panel axial buckling stress
GG	$g(C_1, C_2, C_3)$	Weight function
SEA4	C4	Ratio of fillet radius to overall depth
SEA5	C5	Ratio of cutting head radius to overall depth
HMAX9	HMAX	Maximum allowable depth
HMIN9	HMIN	Minimum allowable depth
SHEET	SHEET	Sheet length
CHKNX	$2C/R[f(C_1, C_2, C_3)]EH^2$	General instability
SY	σ_{yld}	Yield strength of material
SU	σ_{ult}	Ultimate strength of material
EC	E	Modulus of elasticity of material
WAFWAT	w	Weight per surface area of sheet
RN	R_n	Cutting head radius
RWS	R_{ws}	Fillet head radius
PROP (II, 6)	TSMIN	Minimum gage thickness
PROP (II, 5)	TWSMIN	Minimum rib thickness
CC6	C6	Ratio of skin thickness to rib spacing
CC7	C7	Ratio of rib thickness to rib spacing

Table 4-4

Nomenclature of 90-Degree Waffle (Cont.)

FORTRAN Symbol	Engineer Symbol	Description
CC8	C8	Ratio of overall depth to rib spacing
CN(8)	$S.F._{ult}$	Ultimate safety factor
CN(7)	$S.F._{yld}$	Yield safety factor
PROP (I, 1)	ρ	Density of material
PROP (I, 2)	μ	Poisson's ratio
WEIGHT	W	Total weight of section

4.10 WAFFLE HEADS

4.10.1 PROGRAM DESCRIPTION

Subroutine WHEAD has been designed to analyze waffle stiffened heads. It is called directly by the W45MAS and W90MAS routines. The analysis includes the calculation and testing of design parameters until an optimum set is obtained. Once minimum gage requirements and strength requirements are satisfied, the weight is calculated and output with the optimum design parameters.

4.10.2 SPECIAL ATTENTION ITEMS

If there is no compressive loading, subroutine MHEAD is called, since the monocoque analysis will handle the problem sufficiently for strength governed cases.

If A (major axis) is not equal to B (minor axis) and C (height of head) does not equal B, then a major error has occurred and the discontinuity number, A, B, and C are printed out and an exit is called.

4.11 NO-FACE 60-DEGREE CORRUGATION

4.11.1 DESCRIPTION

For general optimization, design parameters are calculated first for zero rings and then for one and more rings. The parameters for zero rings are saved and used as a

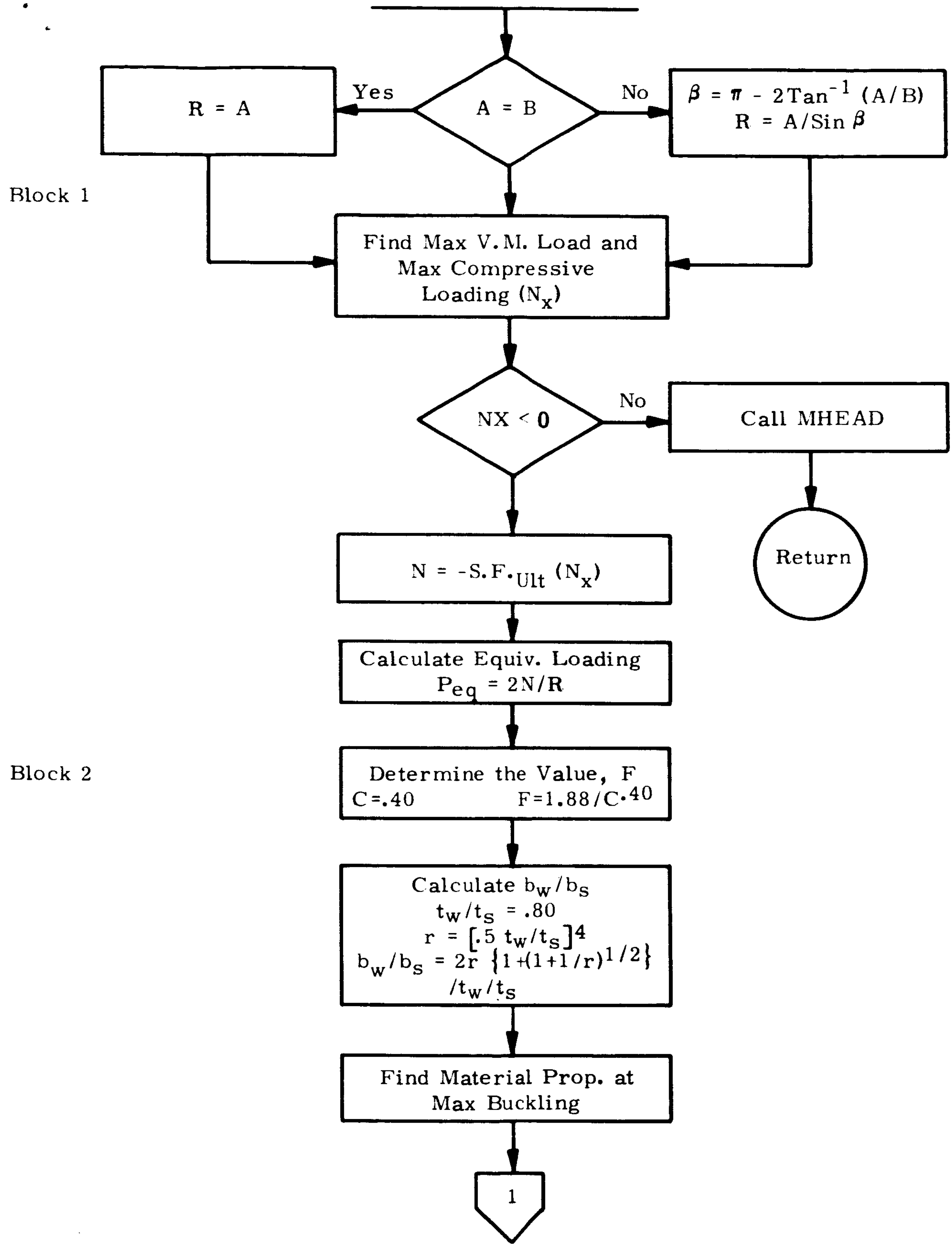


Figure 4-48. Subroutine WHEAD (Sheet 1 of 4)

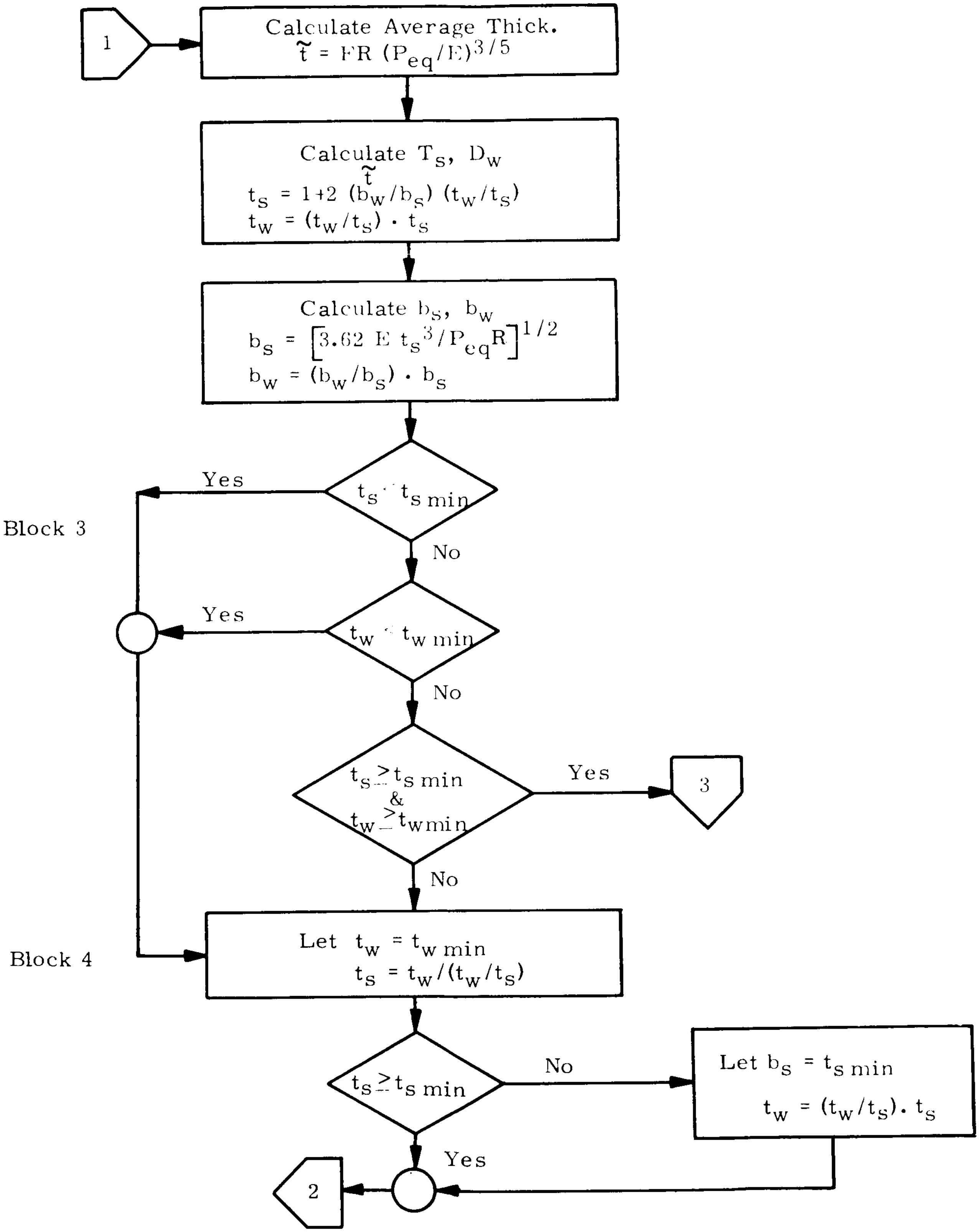


Figure 4-48. Subroutine WHEAD (Sheet 2 of 4)

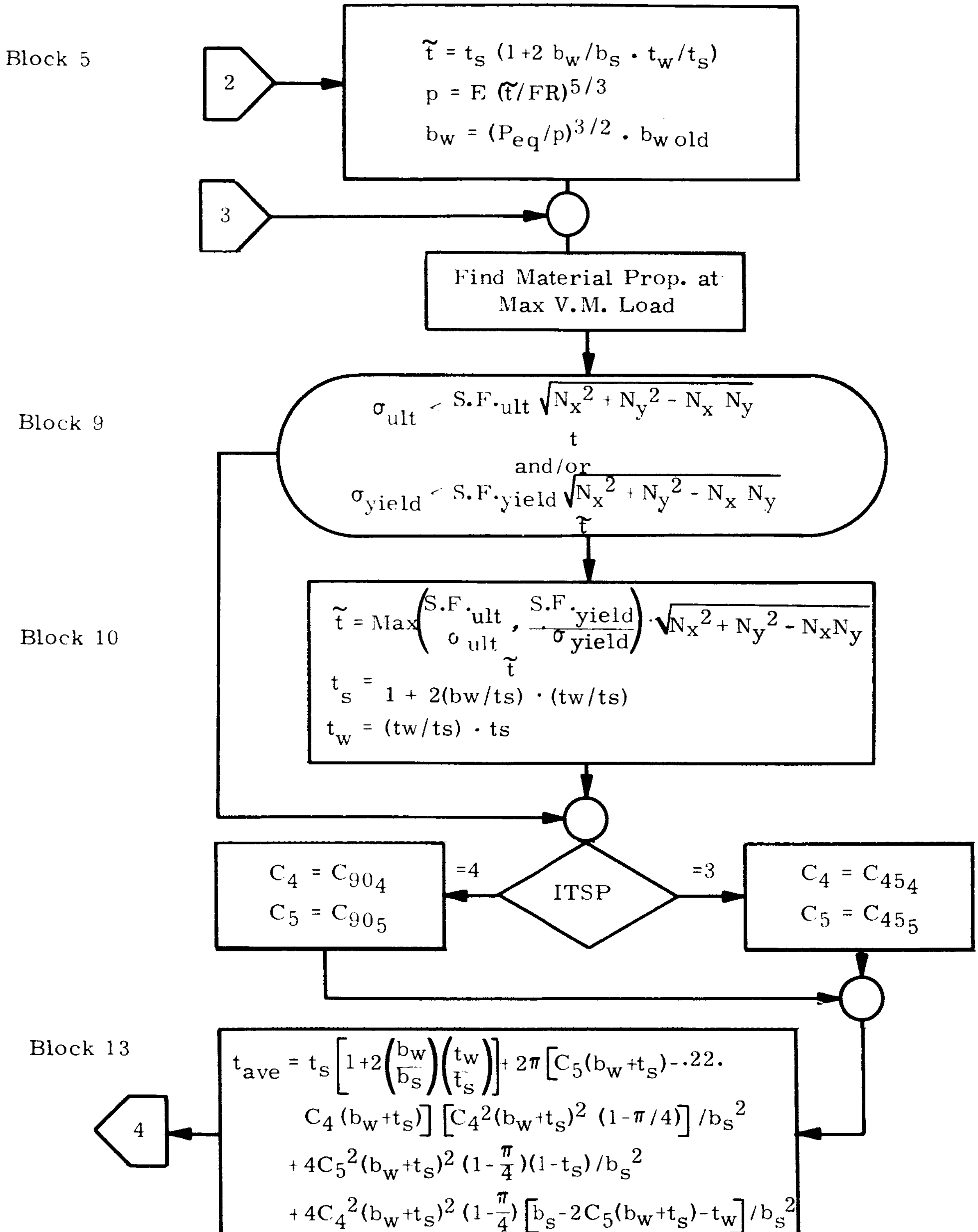


Figure 4-48. Subroutine WHEAD (Sheet 3 of 4)

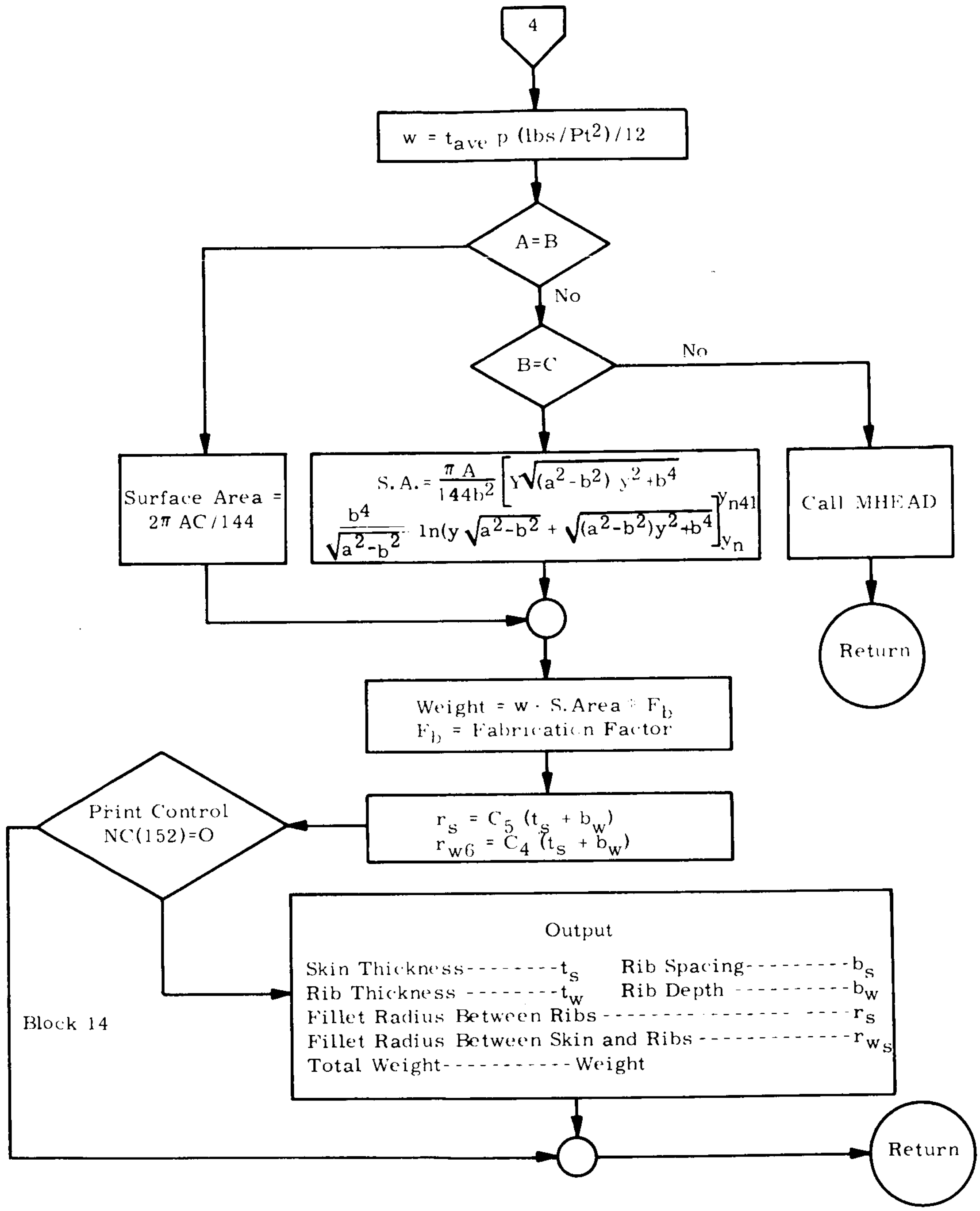


Figure 4-48. Subroutine WHEAD (Sheet 4 of 4)

base for future calculations. Each time the weight is found for a particular number of rings, it is compared to the weight of number of rings -1. If the weight is less, it is stored away and another ring is added. When the weight of the new calculations is greater, it is assumed that the previous stored parameters are the optimum and the sheet is complete.

When all sheets are complete, weights for rings between sheets are calculated and the total weight for the section is computed.

If an error condition is found in either the thickness or depth, the previous set of parameters (number of rings -1) are used for the sheet.

When either the number of rings or the thickness of corrugation is input, an optimization is performed based on the input parameter; parameters are calculated directly. If an error occurs, the option is dropped and the sheet is recalculated by optimization techniques.

If the depth of corrugation is input, optimization is performed. In each case, the thickness is taken to be the larger of the thickness for local crippling and the thickness for Euler buckling. All other procedures are identical to having no options.

Table 4-5

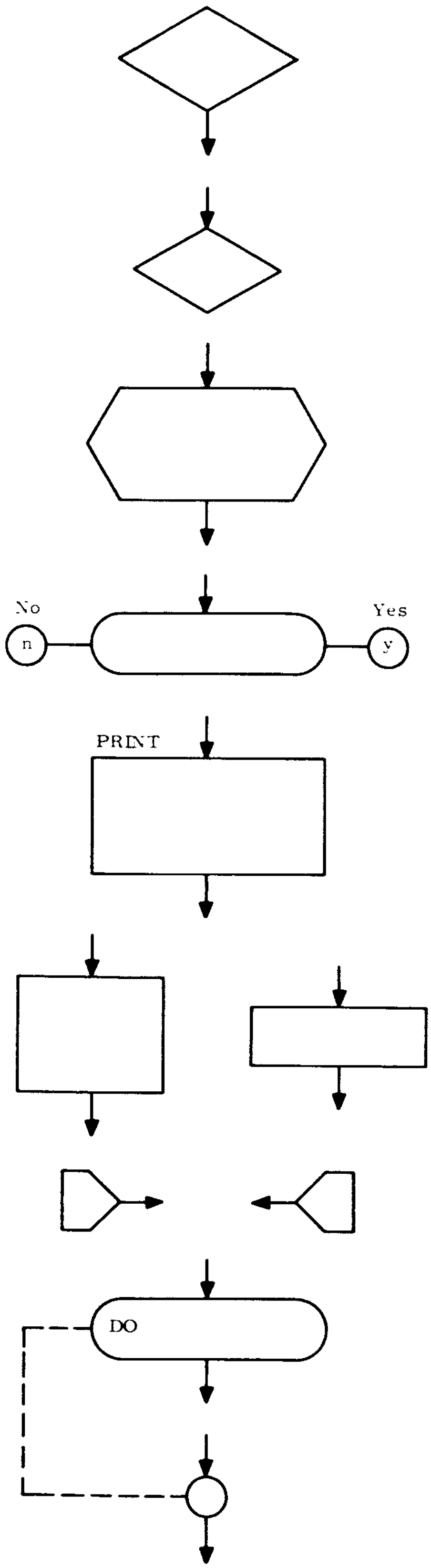
60-Degree Corrugation - Glossary of Terms Used in Flow Chart

Name	Description
N	Sheet counter
SHEET	Input sheet length
NSHEET	Number of sheets in this section
N_y	Maximum N_y buckling over this sheet
N_x	Maximum N_x buckling over this sheet
L	Length of sheet section
R	Average radius of beginning and end stations for this sheet
D	Diameter
E_c	Young's modulus of the core material
E_r	Young's modulus of the ring material
γ_c	Density of core material
γ_r	Density of ring material

Table 4-5

60-Degree Corrugation - Glossary of Terms Used in Flow Chart (Cont.)

Name	Description
INOPT	Input Option 0: No parameters are input 1: Number of rings/sheet are input 2: Thickness of corrugation is input 3: Depth of corrugation is input
COROPT	When INOPT = 1, 2, 3, the value of the option is input as COROPT
t_{cl}	Thickness necessary for local crippling used when INOPT = 3
t_{ce}	Thickness necessary for Euler buckling used when INOPT = 3
t_{cm}	Minimum allowable thickness
t_c	Thickness of corrugation
F	Corrugation compressive stress level
b	Ratio of the unsupported corrugation panel width to the corrugation thickness
P	Pitch of corrugation
d	Depth of corrugation
A	Area of corrugation
WTS	Weight of corrugation shell
WTR	Weight of rings
WT	Sum of WTS and WTR
RING	Number of rings for this sheet
BAYS	Number of bays for this sheet
WTRNG	Weight of ring between two sheets
WEIGHT	Total weight of this section
	Meaning of Subscripts Used In Flow Chart
0	Indicates calculation for sheet with no rings. Used in ratios to form new values.
1	First set of values to use in comparison for optimum parameters
n	Second set of values to use in comparison. If second set is more optimum, the loop continues and all n subscripts are stored as 1 subscripts.
N	Refers to final sheet parameters
d_{min}	Minimum allowable depth
d_{max}	Maximum allowable depth
$t_{c_{min}}$	Minimum allowable thickness



Entry point to a routine

Return from a routine
Return - is a normal return
Return - 1, 2, 3, or 4 are non-standard returns

Call to a subroutine to be executed

A question statement, answered by yes or no. An indicator answered by the value of the indicator.

A printed output statement indicating an error or important condition.

A comment statement, store statement or arithmetic equation.

Flow chart connector.
A "GO TO" statement

Beginning of loop. Loop is executed until completed by limits (e.g., I-1, 13) or until some other statement transfers the program out of the loop.

End-of-loop indicator

Figure 4-49. Flow Chart Symbols

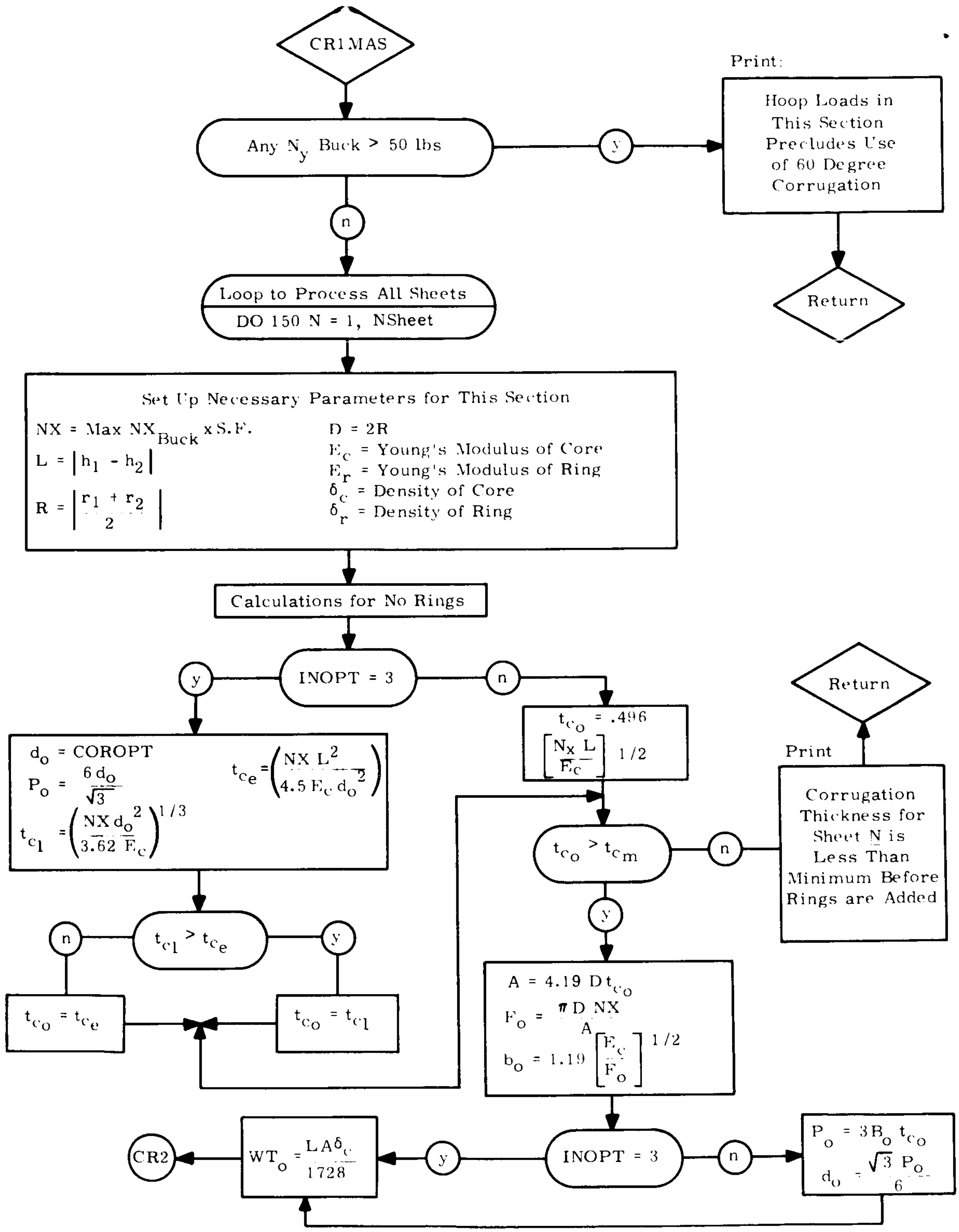


Figure 4-50. CR1MAS Subroutine Flow Chart (Sheet 1 of 4)

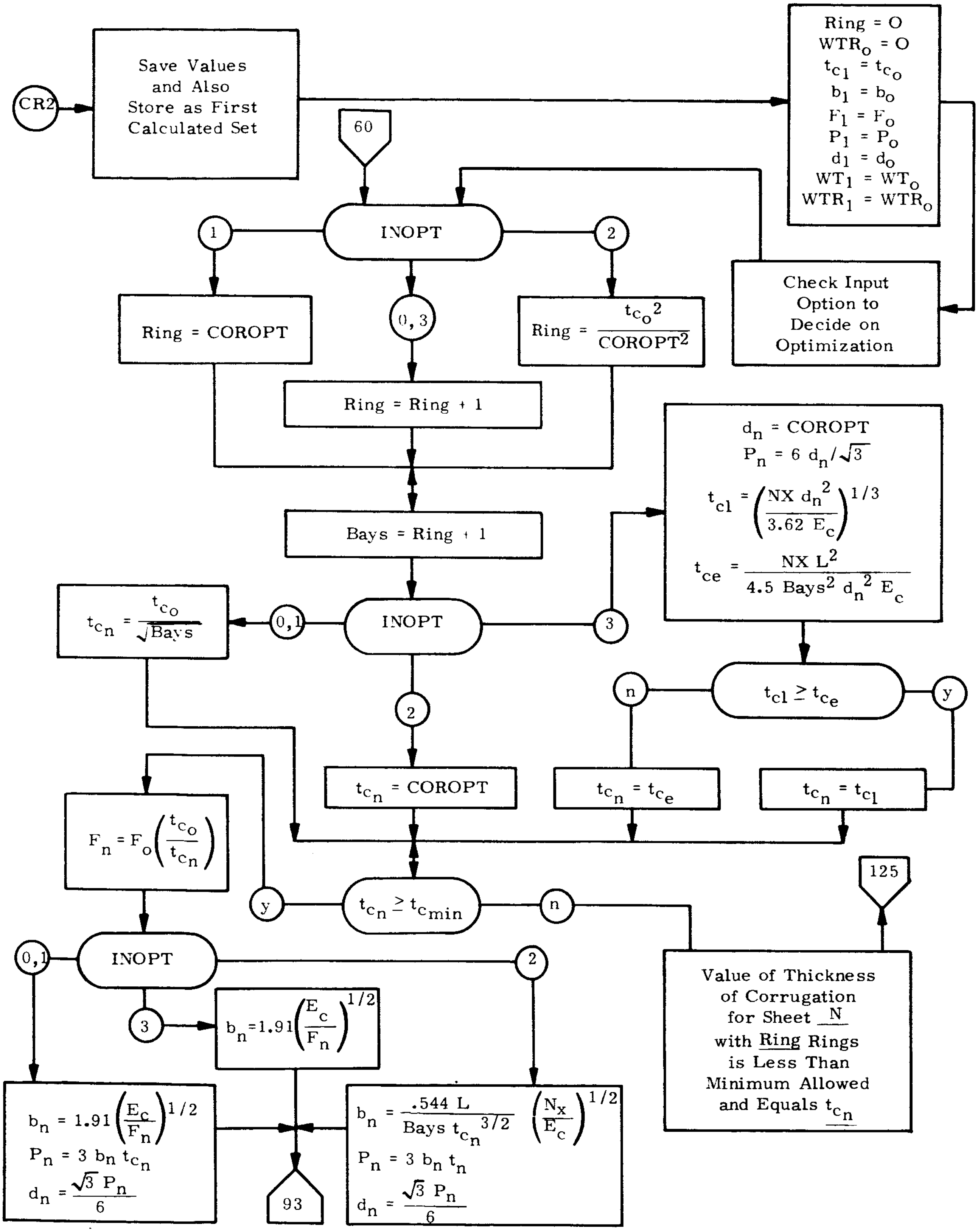


Figure 4-50. CR1MAS Subroutine Flow Chart (Sheet 2 of 4)

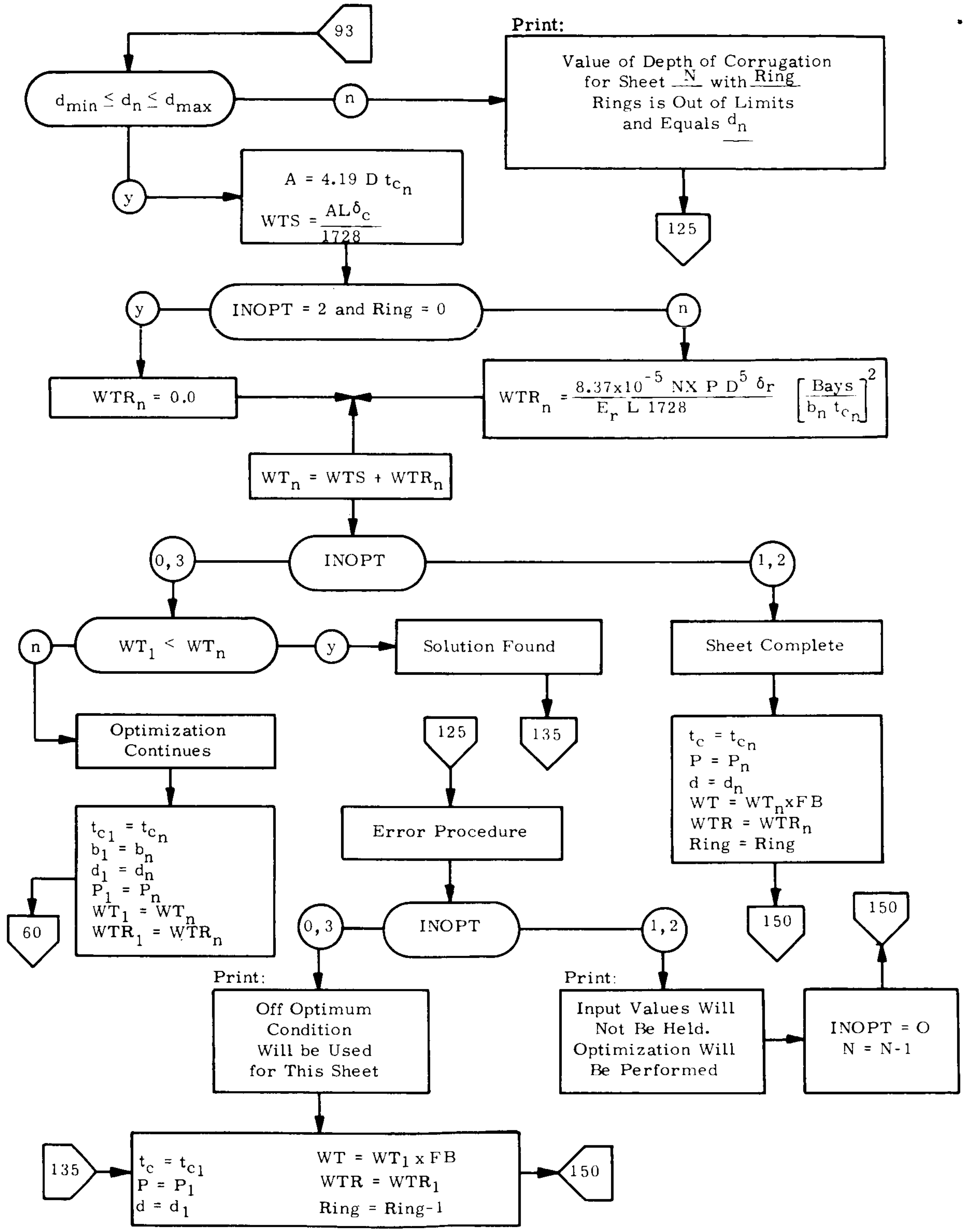


Figure 4-50. CR1MAS Subroutine Flow Chart (Sheet 3 of 4)

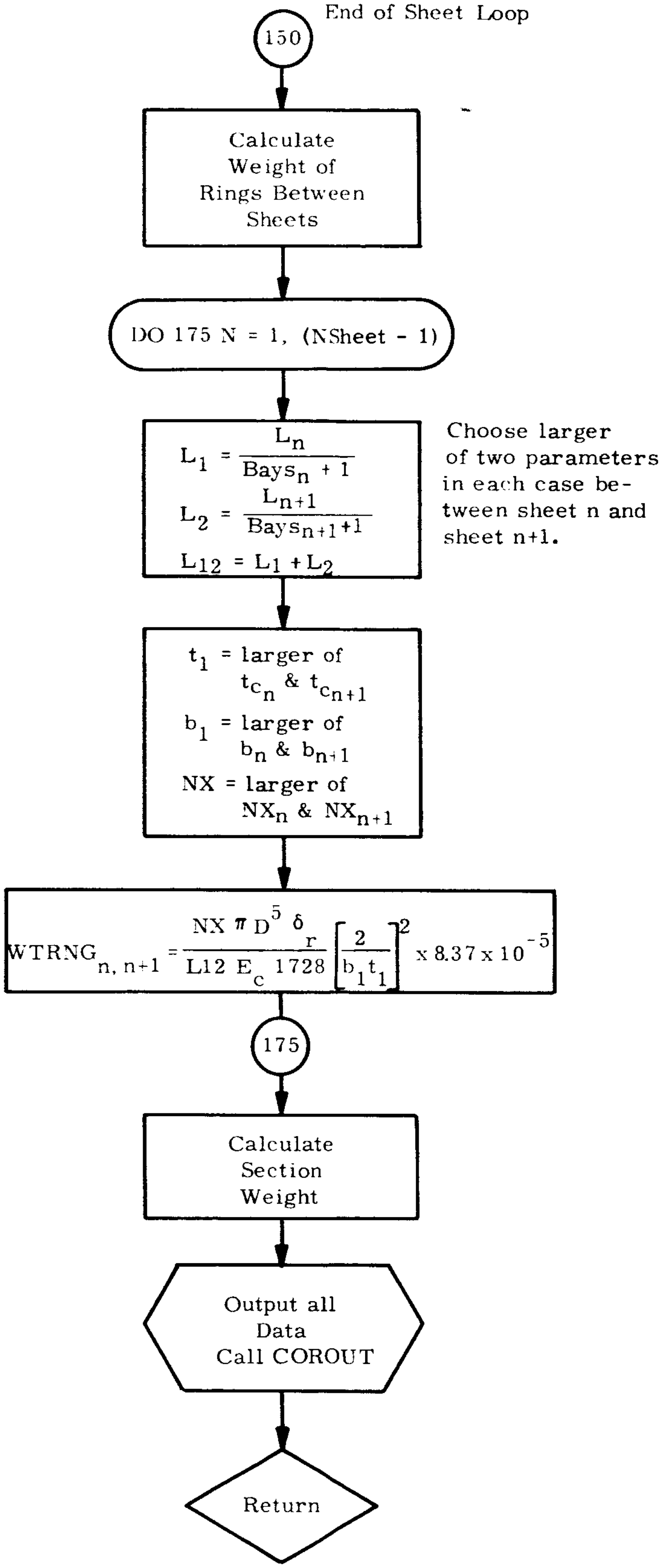


Figure 4-50. CR1MAS Subroutine Flow Chart (Sheet 4 of 4)

4.12 SINGLE-FACE CORRUGATION

4.12.1 INTRODUCTION

Given a section divided into equal length sheets, this subroutine will calculate the strength/weight ratios as functions of C_1, C_2, and C_3 (predefined parameters) and store the ratios in descending order. Choosing the largest strength/weight ratio, the corresponding C_1, C_2, and C_3 will be assumed optimum for testing purposes. If local buckling, panel buckling, or maximum corrugation height is violated, the next largest value of the strength/weight ratio is chosen and testing is repeated until no test is violated.

C_1	20	25	30	35	40
C_2	20	25	30	35	40
C_3	500	1200	1900	2600	3300

The strength is then checked and new design parameters calculated. If strength governs, a new corrugation thickness will be calculated and new design parameters to satisfy strength requirements before further testing. In either case, i.e., strength governing or buckling governing, minimum gage is checked and if satisfied, weight is then calculated and output immediately with the corresponding geometry information. If minimum gage is violated, it must be satisfied and ring spacing increased prior to calculation of weight and output.

4.12.2 ROUTINE TROUBLE SPOTS AND POSSIBLE CORRECTIONS

4.12.2.1 CR1MAS (1)

Hoop loads in this section preclude use of 60-degree corrugation. (Self-explanatory.)

4.12.2.2 CR1MAS (2)

Corrugation thickness for sheet ___ is less than minimum before rings are added. It is impossible to reduce skin thickness to optimize weight. Either reduce minimum thickness or ignore this construction.

4.12.2.3 CR1MAS (3)

Value of thickness of corrugation for sheet ___ with ___ rings is less than minimum allowed and equals ___. The addition of this ring causes an error. Calculation continues with the latest number of rings not causing an error. Possibly adjust minimum

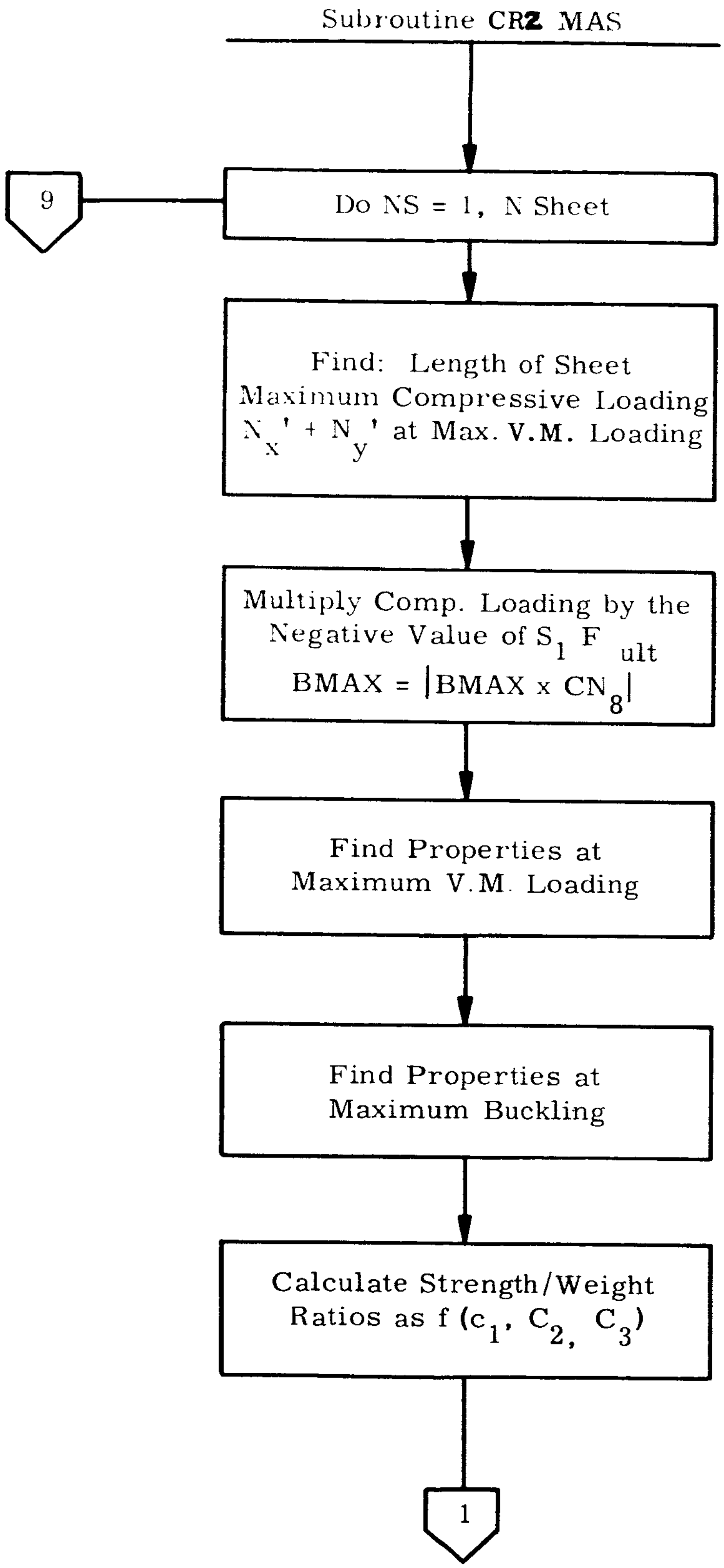


Figure 4-51. CR2MAS Subroutine Flow Chart (Sheet 1 of 9)

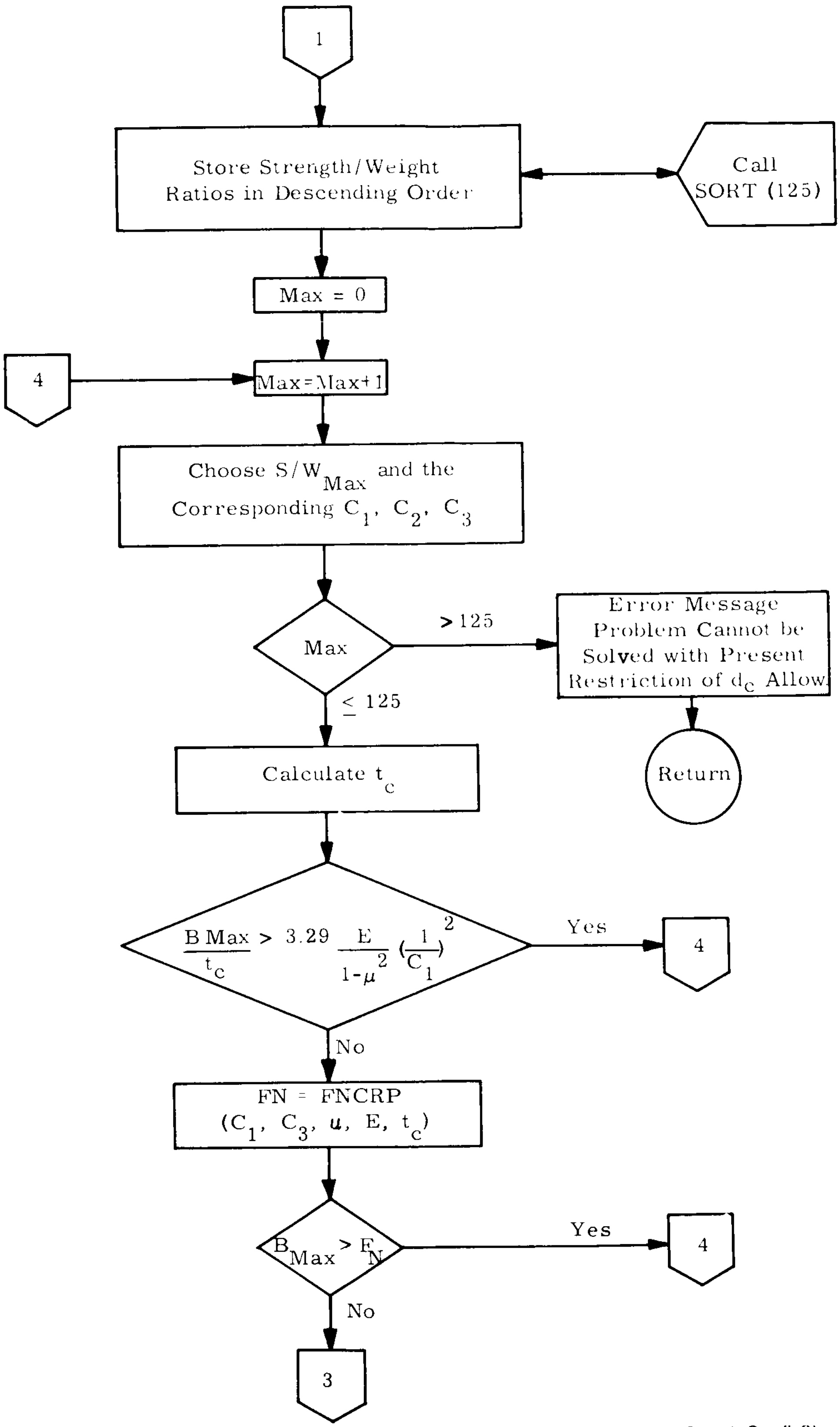


Figure 4-51. CR2MAS Subroutine Flow Chart (Sheet 2 of 9)

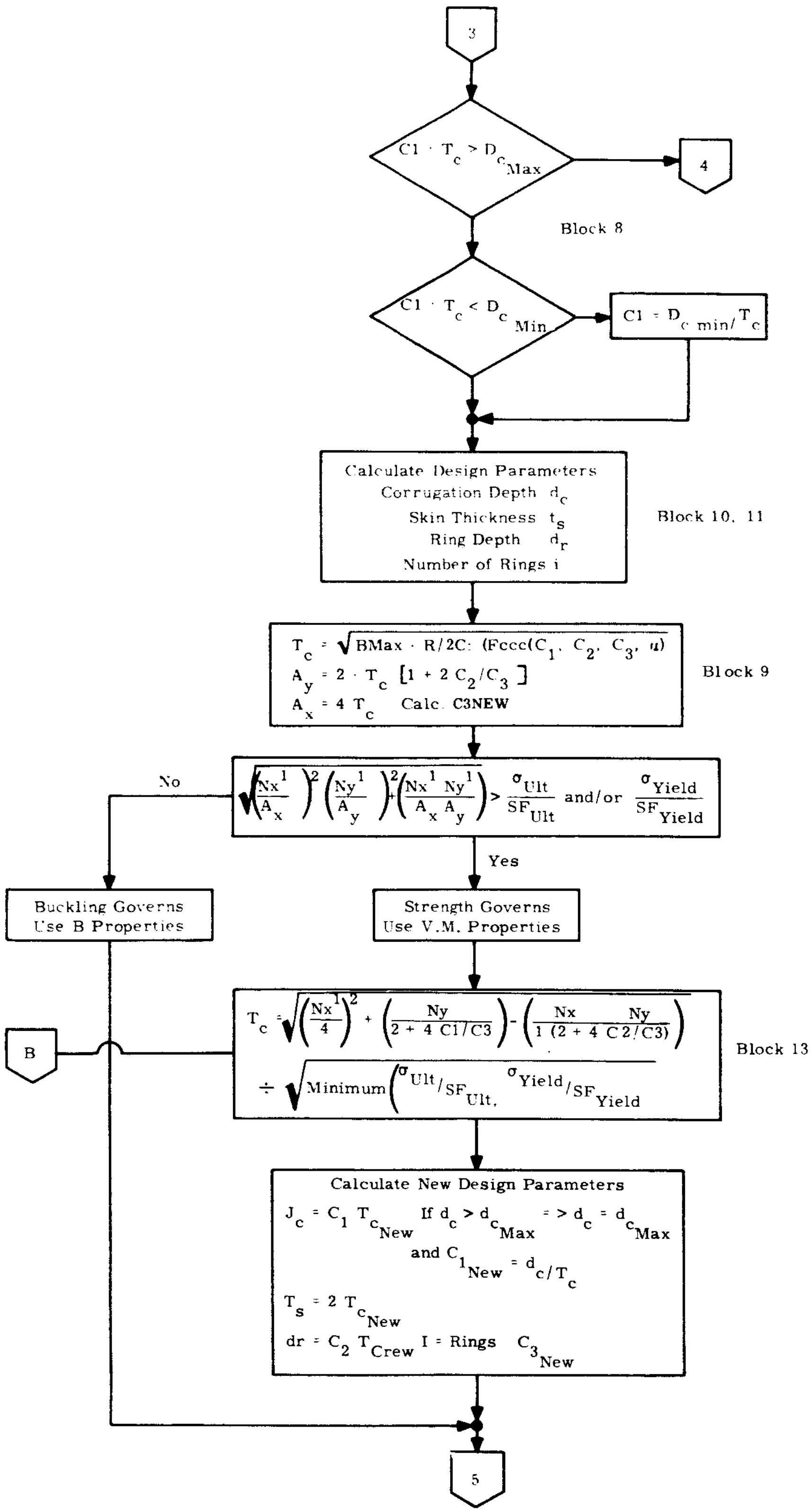


Figure 4-51. CR2MAS Subroutine Flow Chart (Sheet 3 of 9)

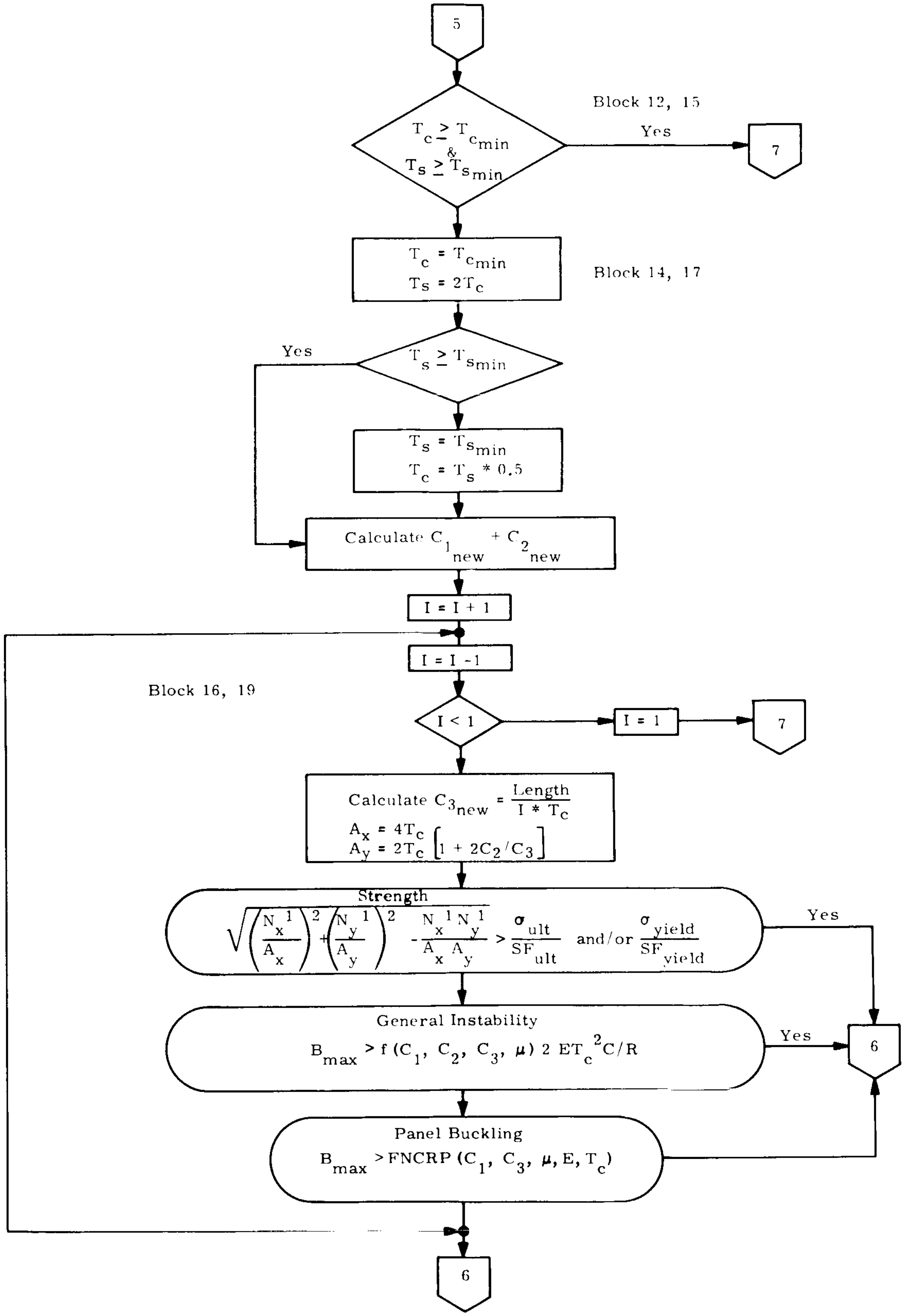


Figure 4-51. CR2MAS Subroutine Flow Chart (Sheet 4 of 9)

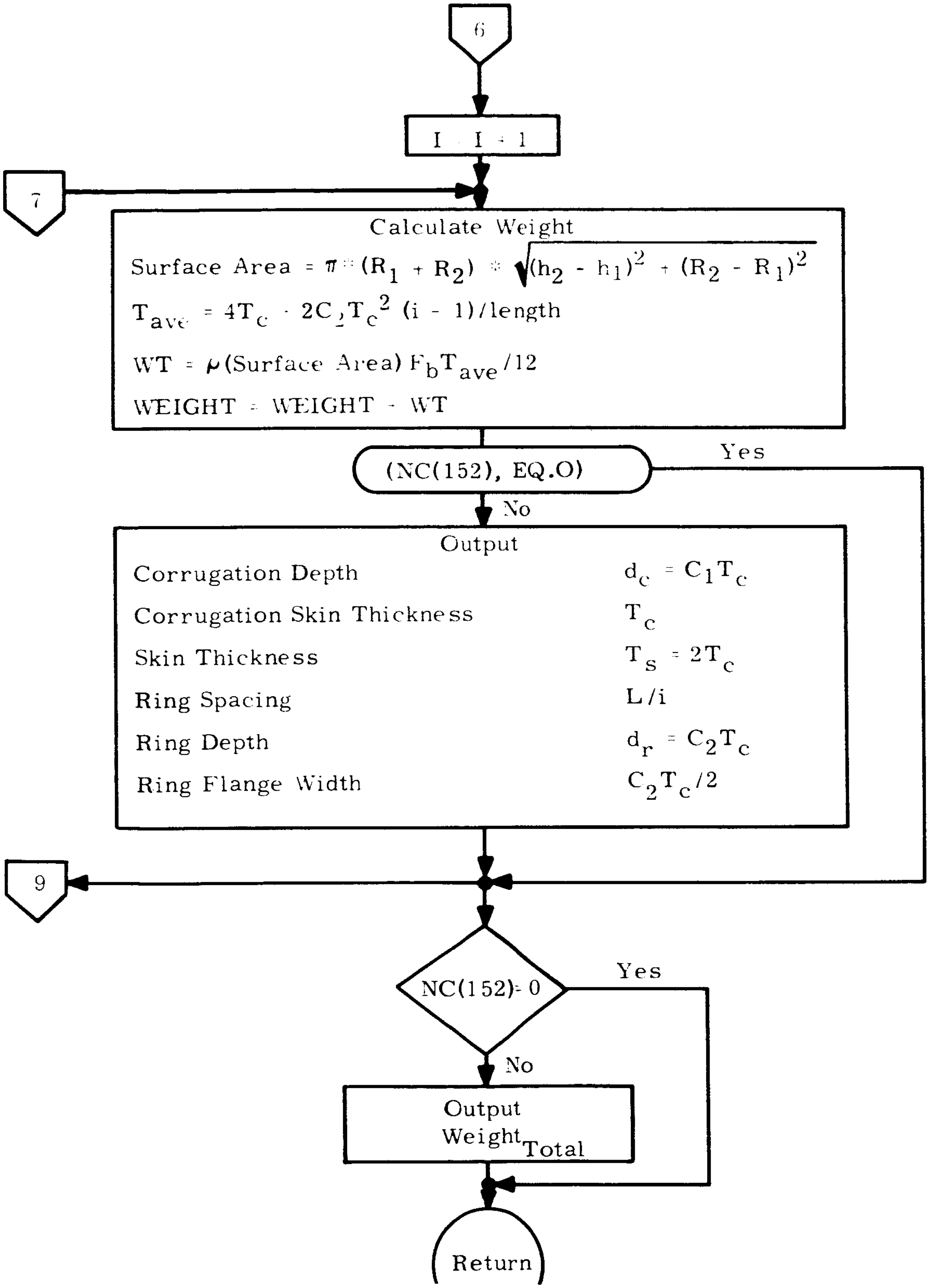


Figure 4-51. CR2MAS Subroutine Flow Chart (Sheet 5 of 9)

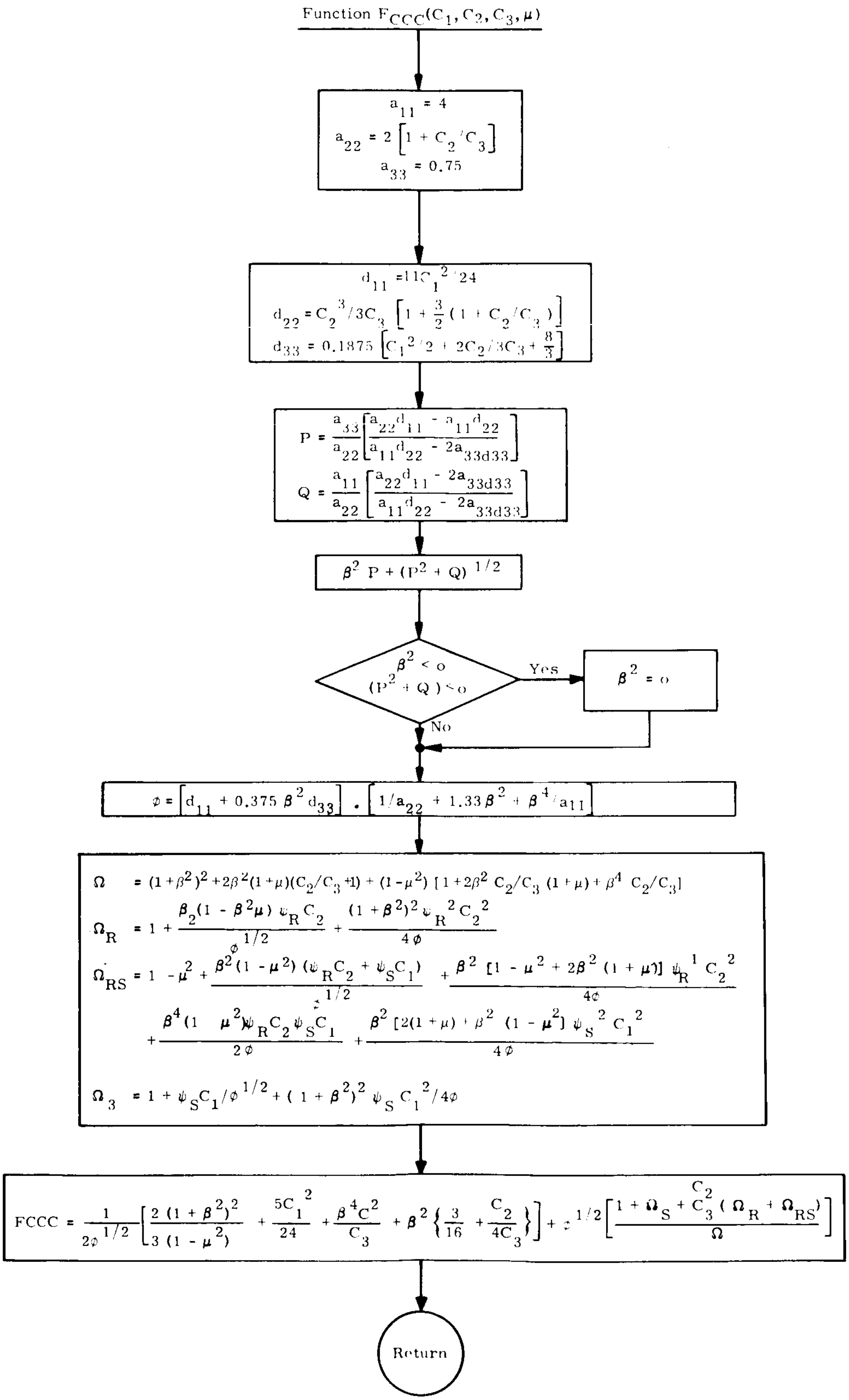


Figure 4-51. CR2MAS Subroutine Flow Chart (Sheet 6 of 9)

d_c Input Option

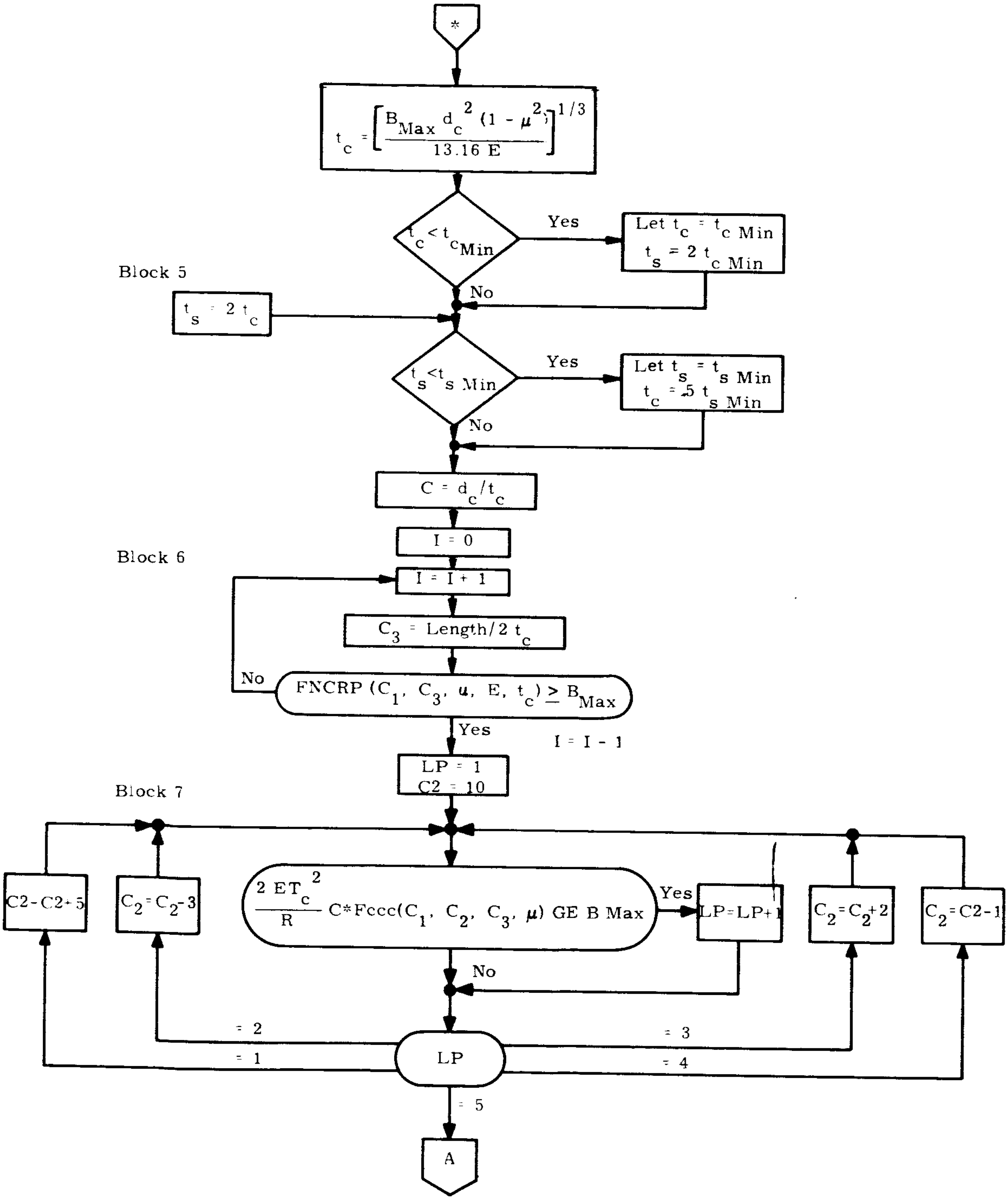


Figure 4-51. CR2MAS Subroutine Flow Chart (Sheet 7 of 9)

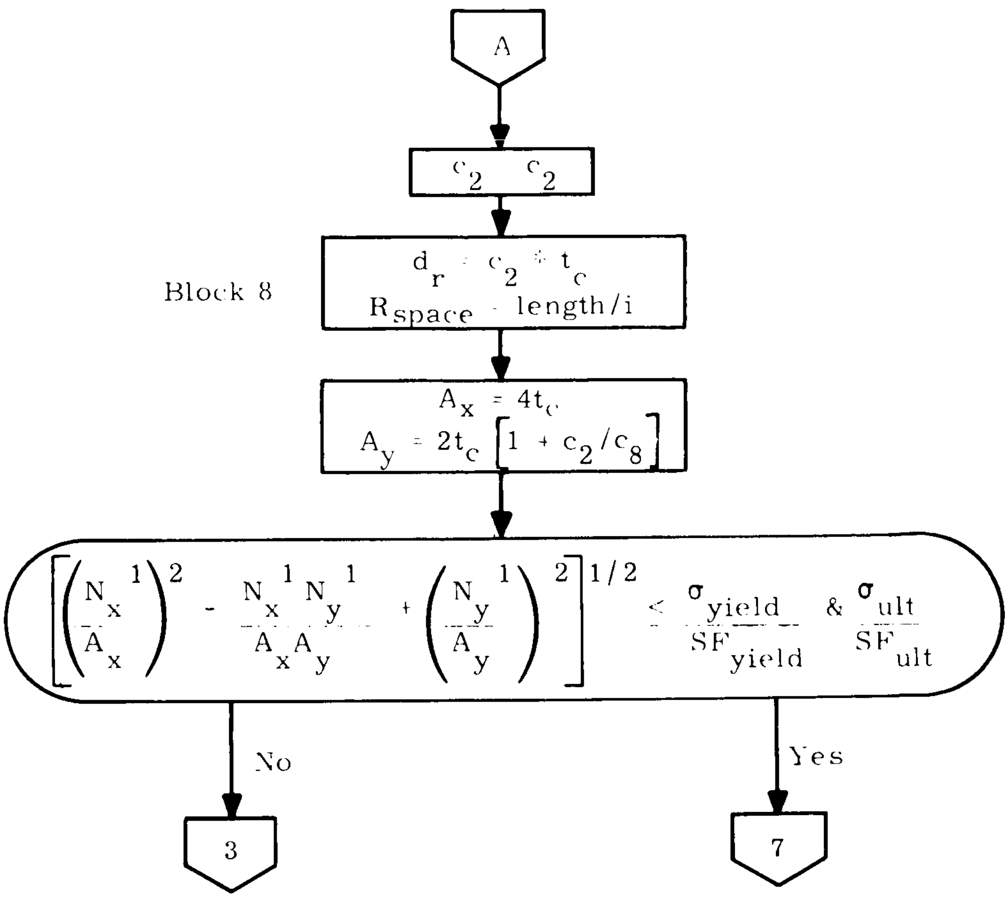


Figure 4-51. CR2MAS Subroutine Flow Chart (Sheet 8 of 9)

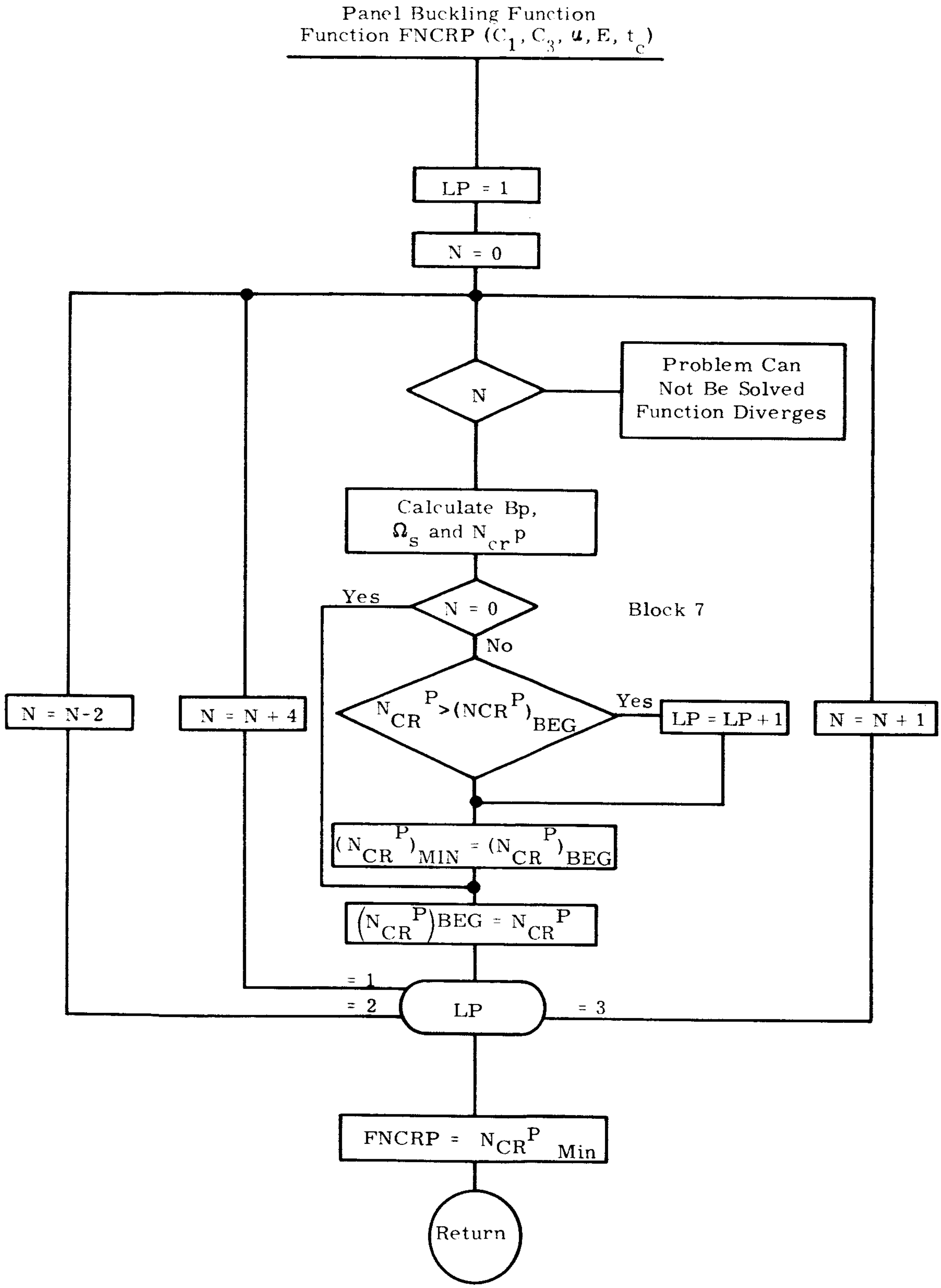


Figure 4-51. CR2MAS Subroutine Flow Chart (Sheet 9 of 9)

4.12.2.4 CR1MAS (4)

Value of depth of corrugation for sheet ___ with ___ rings is out of limits and equals ___. The latest number of rings not causing an error will be used in calculation. Possibly adjust minimum.

4.12.2.5 CR1MAS (5)

Off optimum condition will be used for this sheet. If errors 4.12.2.3 or 4.12.2.4 occur during an optimization run, this message is printed out to indicate answers are off optimum.

4.12.2.6 CR1MAS (6)

Input values will not be held. Optimization will be performed. If errors 4.12.2.3 and 4.12.2.4 occur during an option run, this message is printed out and the sheet is reprocessed in an optimizing run.

4.13 SEMI-MONOCOQUE

4.13.1 DESCRIPTION

This analysis finds the optimum semi-monocoque construction for a particular section with all maximum loading conditions accounted for which will satisfy both buckling and strength requirements. All necessary stringer, flange, and skin measurements are calculated as well as the weight of each sheet and the total section.

The main routine controls the flow of the program and the calling of subroutines. Subroutines are used to calculate parameters and control most iterative processes.

The input options INA and INB are used if a specified value is desired for any applicable parameter. Throughout the execution of the program, these options can change in number if a value becomes fixed either by bounds or by calculation restraints.

If no INB options are input, calculation begins by determining section properties for this sheet. An optimizing loop is executed to determine the best value of the effective modulus of elasticity and its corresponding stress. Based on these parameters, a skin thickness t is computed for buckling. Strength requirements are examined and a skin thickness for strength is determined (t_V).

If t is greater than t_v and t_{min}, output values are calculated and checked against their minimum and maximum bounds. If t_v is greatest, t is made equal to the t_v and an iteration begins to determine the best skin thickness to satisfy both buckling and strength. If t_{min} (minimum thickness) governs, t is set equal to t_{min} and becomes the fixed value.

If an error condition occurs, such as a value being too large or too small, it is set to its closer bound and becomes a fixed parameter.

If a skin or stringer option is indicated (a fixed parameter input) or if there exists a fixed parameter from the first part of the program, the logic moves on further.

Here an optimizing iteration determines the best efficiency factor (F), modulus of elasticity and stress level based on this fixed parameter. The value of F is found by a linear interpolation in Table 4-6.

Testing is again done on the new t versus t_v versus t_{min} as described above. If t must be changed and was originally fixed, it can be changed, but if a second parameter becomes fixed, calculation of the sheet is abandoned and weight is determined for the latest values calculated.

Input of the INA options eliminate calculations of certain parameters, and partially determine values of others, but at no time are these considered "fixed" parameters to alter the logic of the program.

4.13.2 SUBROUTINE FUNCTIONS

4.13.2.1 INSEM

Stores input data by option on INA and INB. Tests values against bound and returns. IERR = 0, no input errors. IERR = 1, an input error occurred.

4.13.2.2 NSECT

Calculates all necessary values for this sheet to initiate processing for buckling and strength.

4.13.2.3 LOOP1

Iterates to find a stabilized value of the effective modulus of elasticity and stress level. Error messages (see flow chart) are printed out if the function diverges or if a specified number of iterations produces no answer. Usually the last values obtained will be used to continue calculations.

4.13.2.4 CHKBND

Checks if frame spacing is within bounds. If it is not, it is set to its closer bound and an alternate return is indicated.

4.13.2.5 CKBND1

Checks if t_f, b, b_s, and t_s are in bounds. The number of errors are counted, the parameters are set to the closer bound, and the suitable alternate return is made.

4.13.2.6 LOOP2

Iterates to find a stabilized value of the efficiency factor. Checks the function for divergence or for no solution after a specified number of iterations. The solution of the efficiency factor is based here on a known parameter. Also calculated are E_p, σ, β, τ, and L.

4.13.2.7 SIEP

Calculates a new stress level based on a newly found efficiency factor. Calculates a new effective modulus of elasticity based on this stress.

4.13.2.8 SOLVE

Interpolates in a table of corresponding values of the known parameter and efficiency factors to determine the value of F. JERR = 0, no error, F found. JERR = 1, F out of range of table.

4.13.2.9 TBCHK

For the known parameter t, t_s, b, or b_s, the corresponding values of the other parameters are calculated. The values are not final, but are mathematically similar, thus ratios between them are valid. τ and β are calculated as these ratios.

4.13.2.10 TCALC

Calculates buckling and strength parameters. including skin thicknesses necessary to sustain each.

4.13.2.11 NCALC

Calculates all necessary output parameters, making sure not to recalculate any parameters set by options or fixed in the program.

4.13.2.12 AOUT

Outputs all sheet data and design parameters.

4.13.2.13 BLOCK DATA

Stores the values given in Table 4-6.

Table 4-6

Semi-Monocoque Glossary of Terms Used in Flow Chart

Program Storage	External Name	Description
THICK (N, 10)	b_f	Frame height
THICK (N, 8)	b	Stringer pitch
THICK (N, 9)	b_s	Stringer height
THICK (N, 6)	t	Skin thickness
THICK (N, 7)	t_s	Stringer thickness
THICK (N, 11)	t_f	Frame thickness
THICK (N, 12)	d_f	Frame flange length
THICK (N, 13)	d_s	Stringer flange length
SEMI (1)	$\bar{t}$	Average thickness of stringer stiffened panel
SEMI (2)	$\bar{t}_f$	A_f/L equivalent frame thickness per unit length
SEMI (3)	$\bar{t}_T$	Average total thickness of frame and stringer stiffened panel
SEMI (4)	t_v	Skin thickness necessary for direct strength requirements
BOUND (5)	t_m	Minimum gage thickness for skin
SEMI (5)	K_x	Ratio of skin thickness to average stringer stiffened panel thickness $t/\bar{t}$

Table 4-6

Semi-Monocoque Glossary of Terms Used in Flow Chart (Cont.)

Program Storage	External Name	Description
SEMI (6)	K_θ	Ratio of skin thickness to average frame stiffened panel thickness $t/t + \bar{t}_f$
NSB	NSB	Maximum buckling
NXVM	N_x	Axial stress resultant for maximum von Mises
NYVM	N_θ	Circumferential stress resultant for maximum von Mises
SEMI (7) SIG	σ	Stress
SITY	σ_{ty}	Tensile yield stress for maximum von Mises
SITU	σ_{tu}	Tensile ultimate stress for maximum von Mises
SIOB	σ_o	Secant yield stress at 0.7 e
S85B	σ_{85}	Secant yield stress at 0.85 e
C	C	Buckling correction factor
FY	F_y	Yield factor of safety
FU	F_u	Ultimate factor of safety
FB	F_b	Fabrication factor
FAC	F	Efficiency factor
EF	EF	Young's modulus
SEMI (8) EP	E_p	Effective modulus of elasticity
THICK (N, 14)	L	Frame spacing
R	R	Radius of shell
TAU	τ	Ratio of t_s/t
BETA	β	Ratio of b_s/b
DEN	γ	Material density
THICK (N, 15)	w	Weight/unit surface area
SA	SA	Surface area
INA	INA	Input option for frame
INB	INB	Input option for skin and stringer
NSHEET	NSHEET	Total number of sheets in this section
N	N	Sheet counter
0	o	Subscript indicating last calculation of a parameter for comparison
N	1 or n	Subscript indicating present calculation for comparison in iterating procedures

Table 4-6

Semi-Monocoque Glossary of Terms Used in Flow Chart (Cont.)

Program Storage	External Name	Description
IERR	IERR	Error indicator
IERR	JERR	Error indicator
TVDIFF DELEP DELF	TVDIFF DELEP DELF	When iterating, the difference between the last value calculated and the present value calculated.

4.13.3 ROUTINE TROUBLE SPOTS AND POSSIBLE CORRECTIONS

4.13.3.1 INSEMI (1)

For input option INA = ___, the input value ___ exceeds bounds. Bound = ___.

4.13.3.2 INSEMI (2)

For input option INB = ___. The input value ___ exceeds bounds. Bound = ___. Inputs are not in correct range. Alter and resubmit.

4.13.3.3 SEMAS (1)

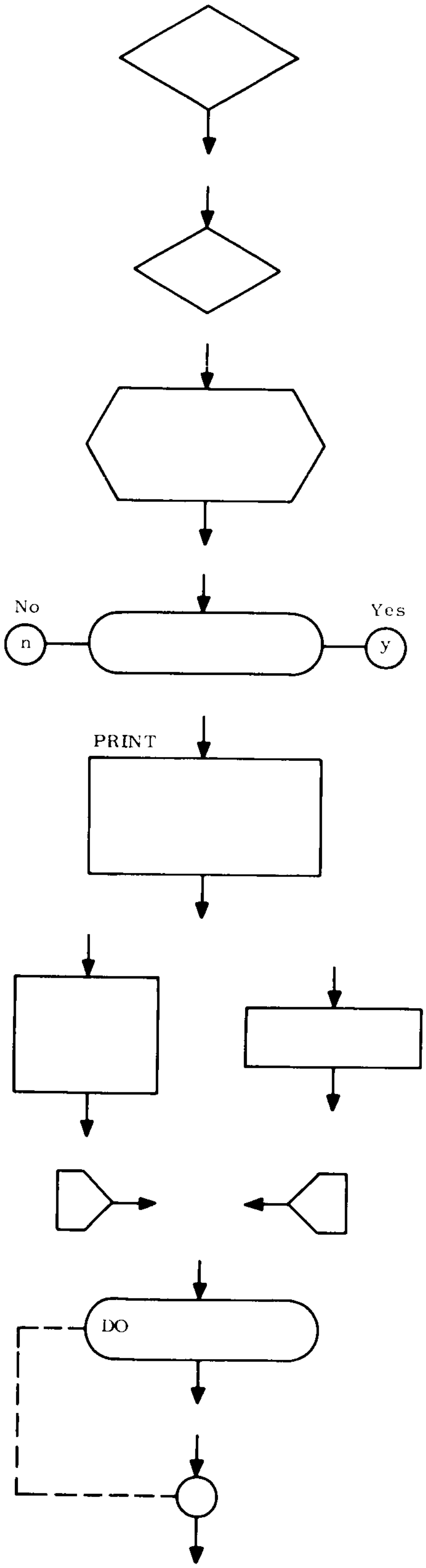
Buckling is the critical design condition for sheet ___. The skin thickness for buckling is greater than that needed for strength. Not an error printout.

4.13.3.4 SEMAS (2)

The value of T was determined by strength requirements for sheet ___. Indicates that strength controls the calculation of parameters.

4.13.3.5 SEMAS (3)

Buckling thickness cannot be made large enough for strength requirements after iterating. T = ___, TV = ___ for sheet ___. Buckling criteria cannot be solved with the present strength requirements, even though 5 iterations were performed to attempt to satisfy both. Weight is calculated and logic ceases. The number of iterations can be increased in the source deck.



Entry point to a routine

Return from a routine
Return - is a normal return
Return - 1, 2, 3, or 4 are non-standard returns

Call to a subroutine to be executed

A question statement, answered by yes or no.
An indicator answered by the value of the indicator.

A printed output statement indicating an error or important condition.

A comment statement, store statement or arithmetic equation.

Flow chart connector.
A "GO TO" statement

Beginning of loop. Loop is executed until completed by limits (e.g., I-1, 13) or until some other statement transfers the program out of the loop.

End-of-loop indicator

Figure 4-52. Flow Chart Symbols

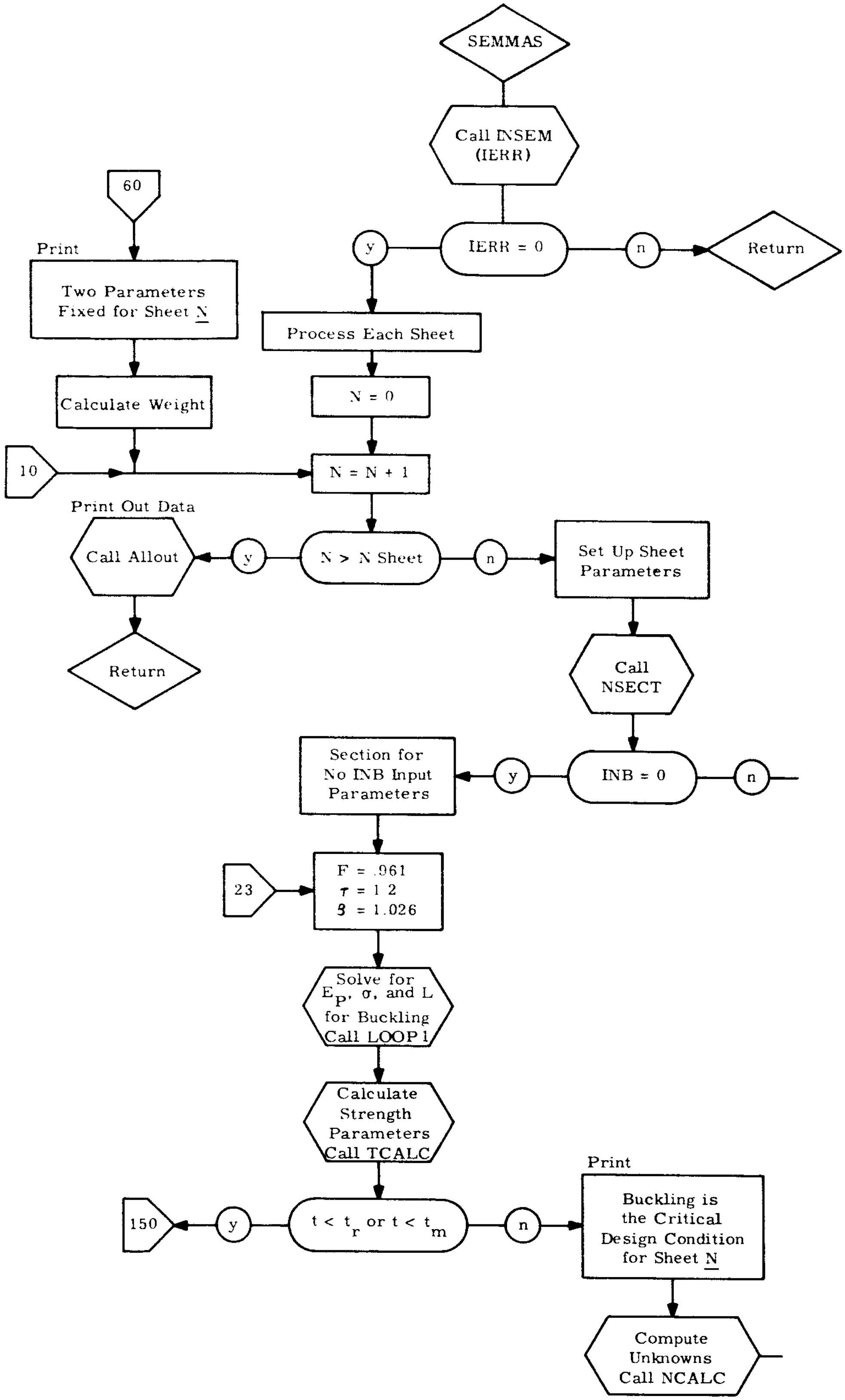


Figure 4-53. SEMMAS Flow Chart (Sheet 1 of 5)

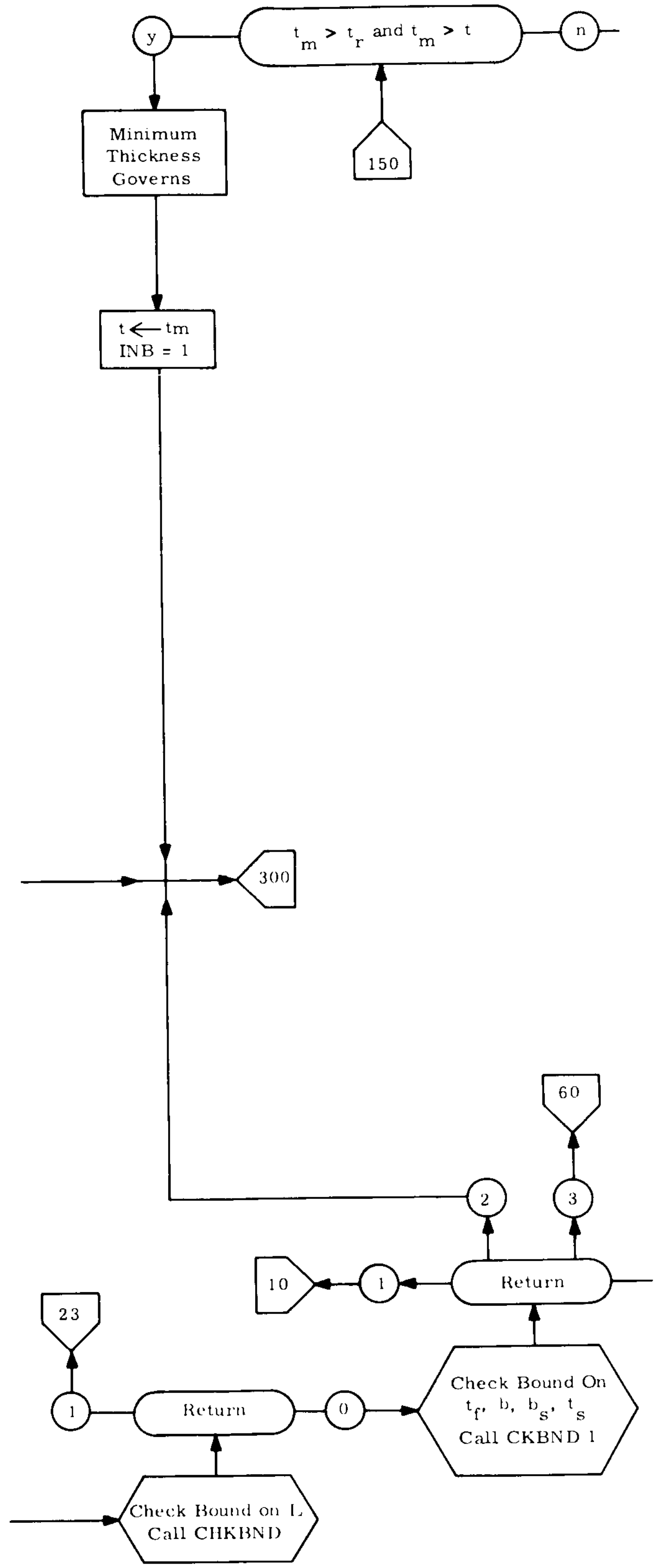


Figure 4-53. SEMMAS Flow Chart (Sheet 2 of 5)

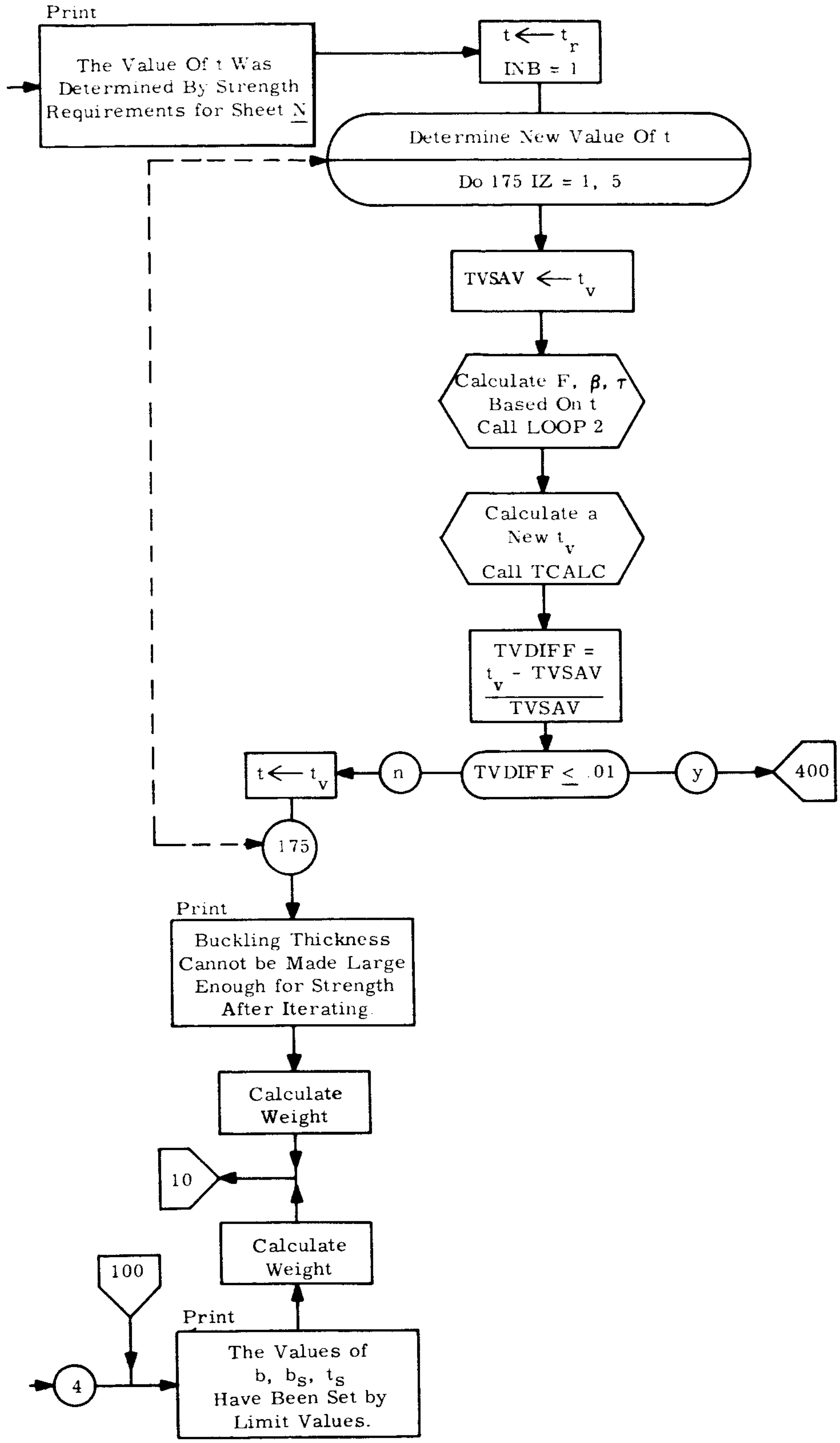


Figure 4-53. SEMMAS Flow Chart (Sheet 3 of 5)

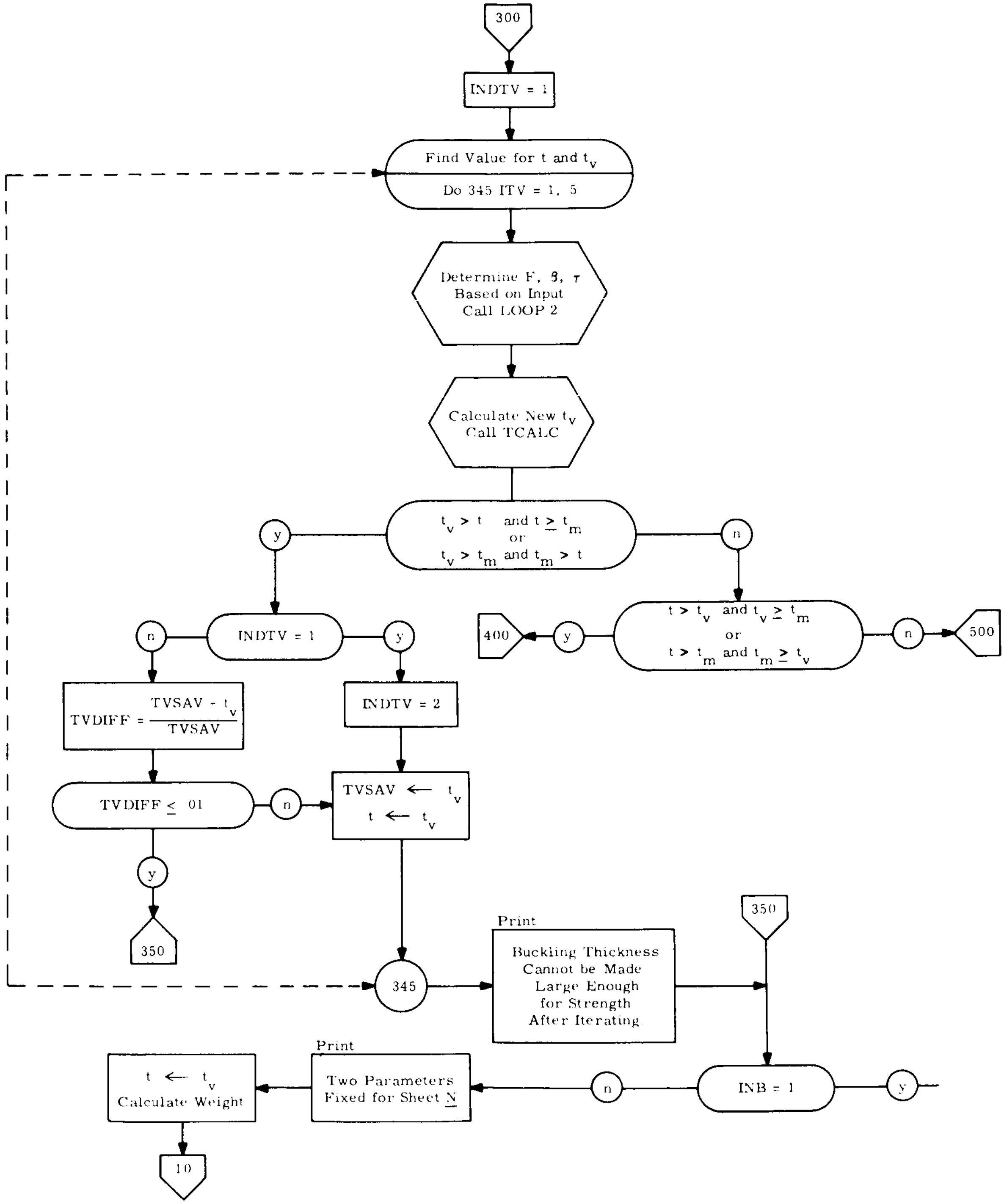


Figure 4-53. SEMMAS Flow Chart (Sheet 4 of 5)

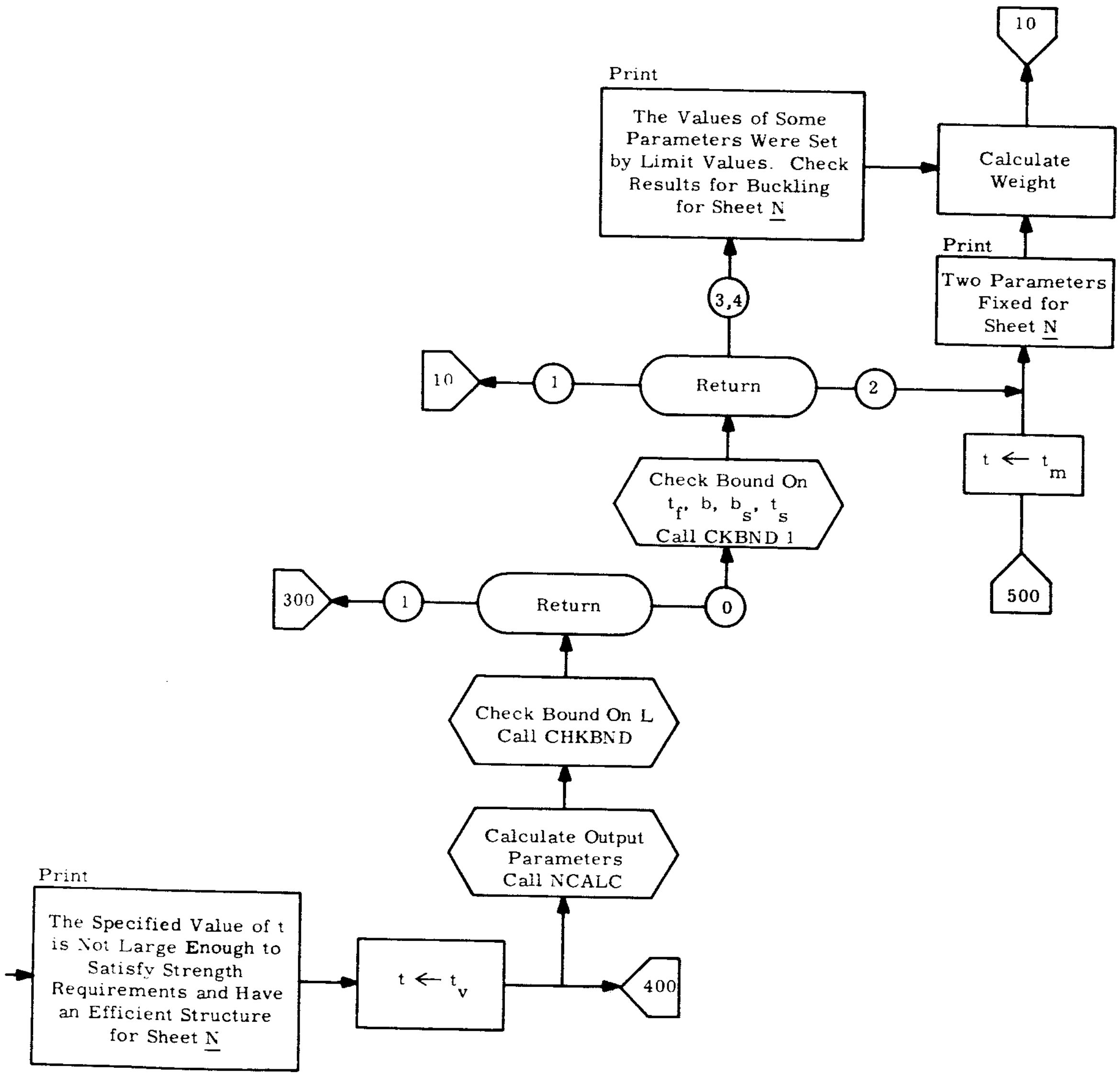


Figure 4-53. SEMMAS Flow Chart (Sheet 5 of 5)

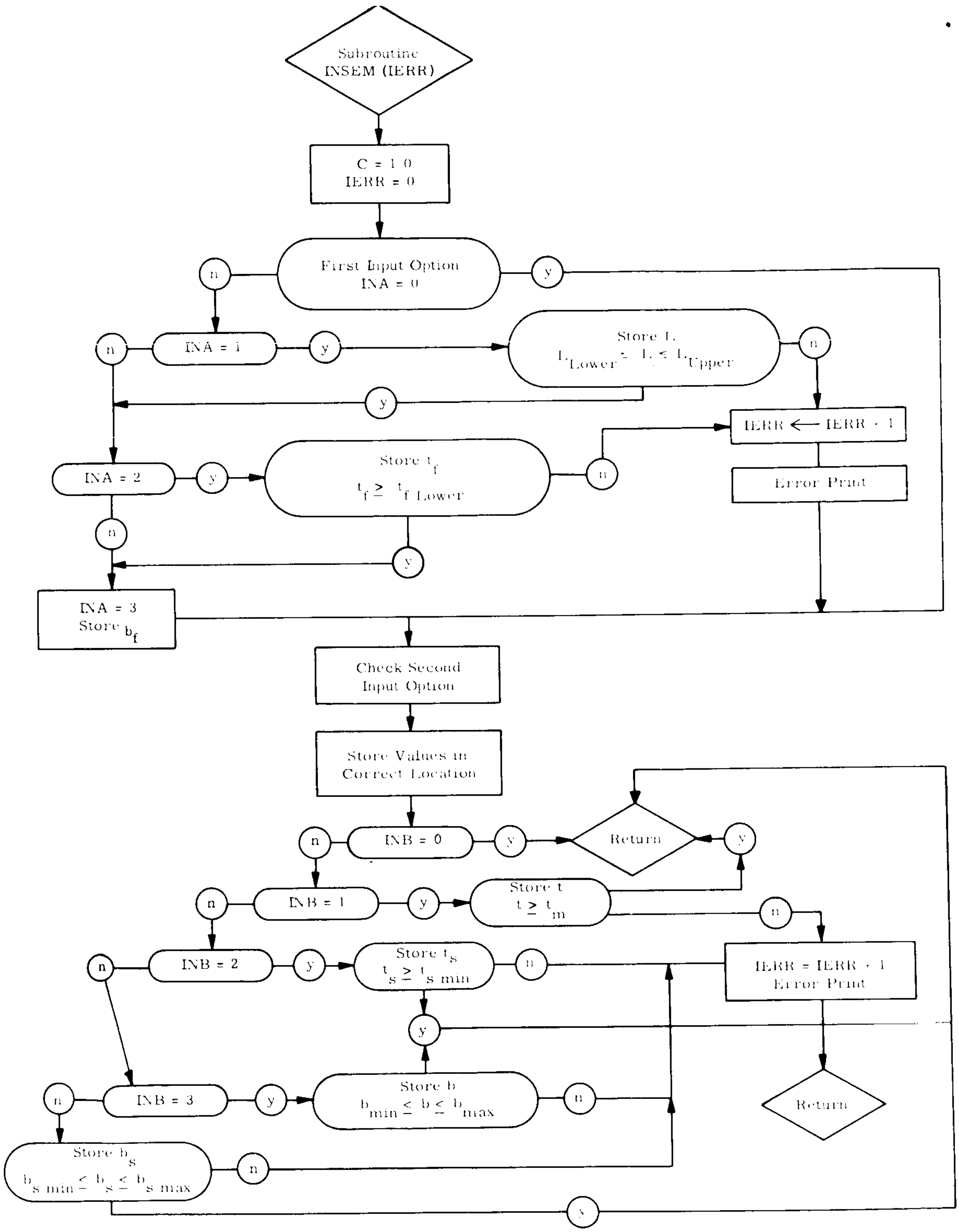


Figure 4-54. INSEM Subroutine Flow Chart

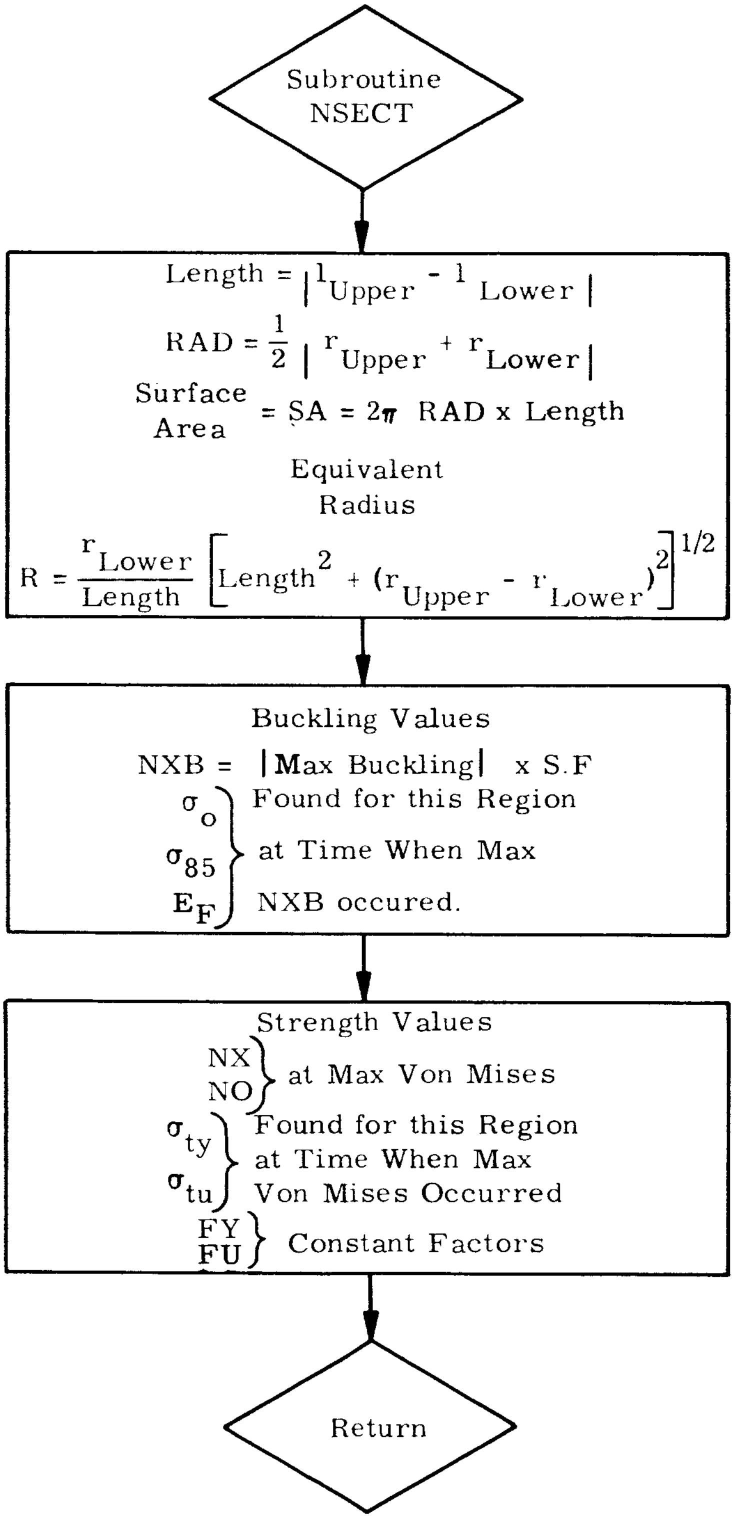


Figure 4-55. NSECT Subroutine Flow Chart

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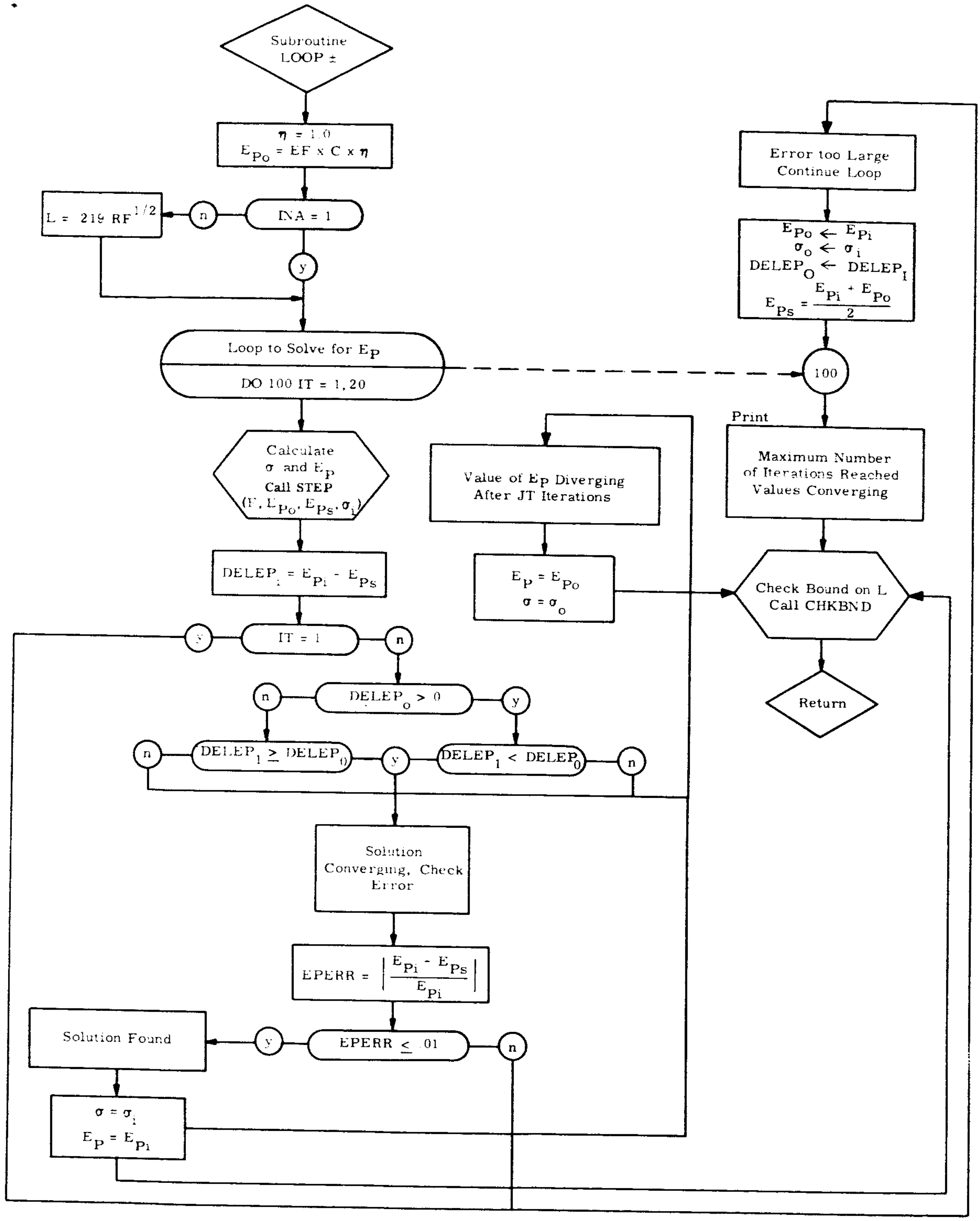

Figure 4-56. LOOP1 Subroutine Flow Chart

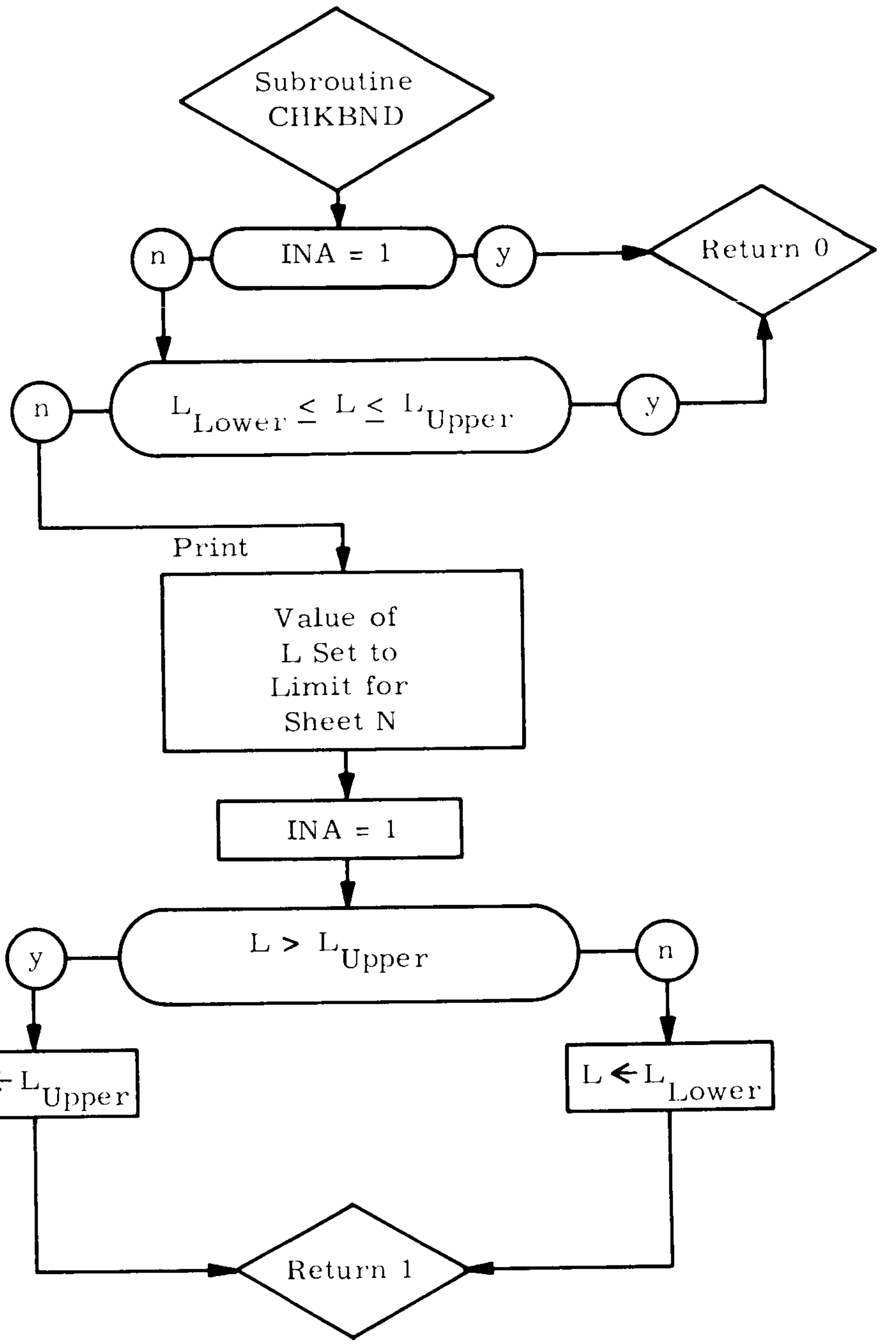

Figure 4-57. CHKBND Subroutine Flow Chart

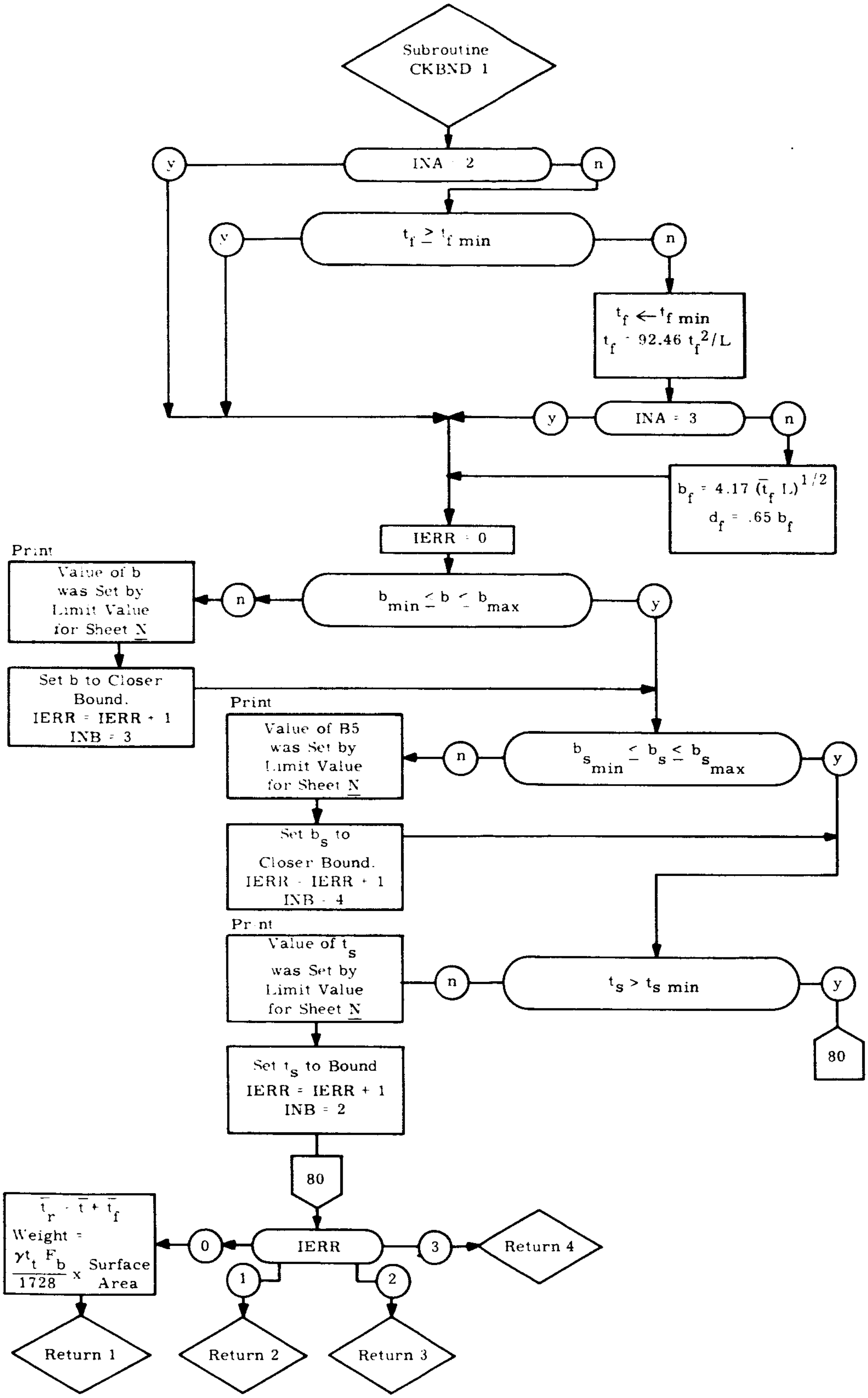

Figure 4-58. CKBND1 Subroutine Flow Chart

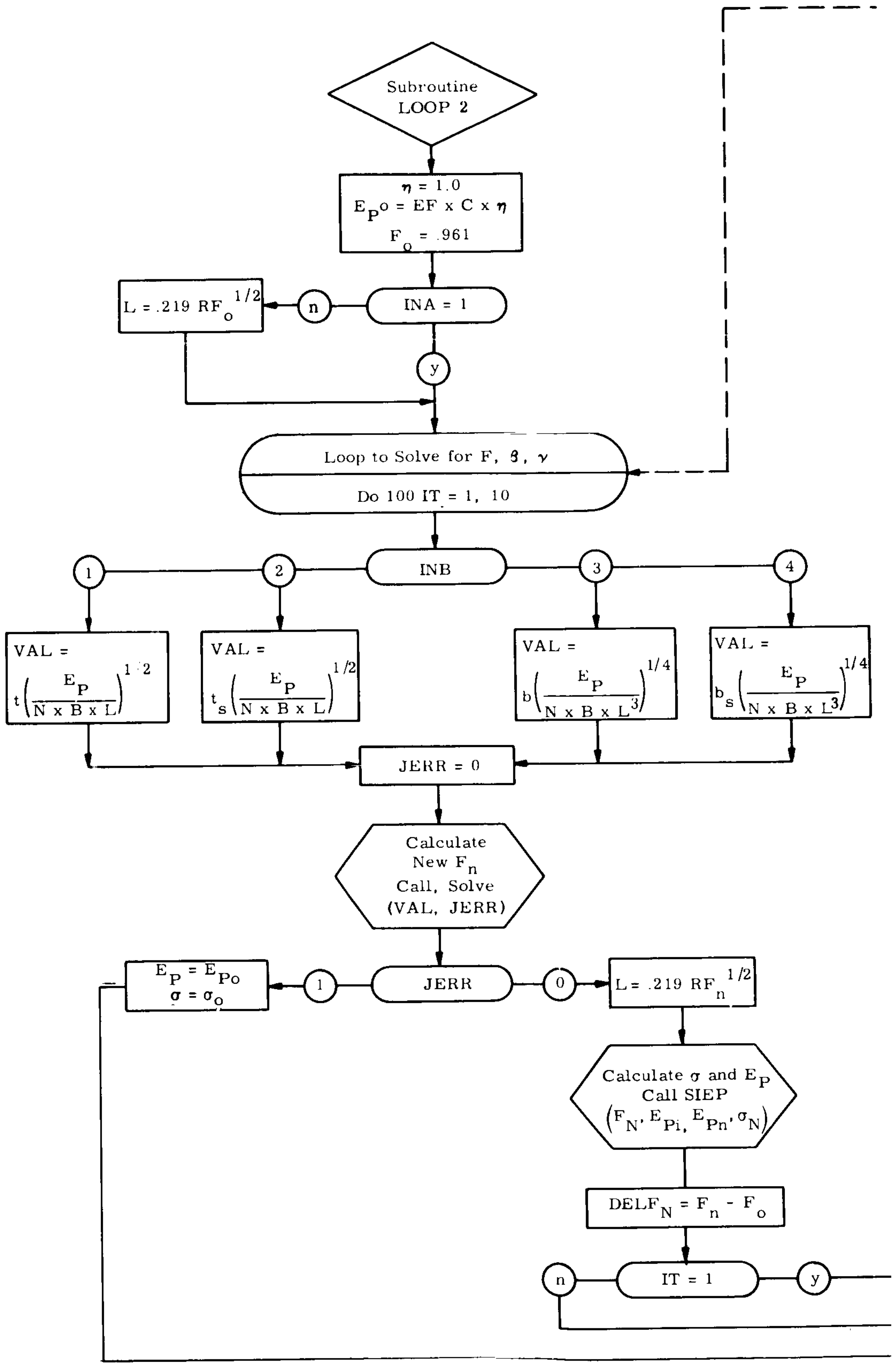

Figure 4-59. LOOP2 Subroutine Flow Chart (Sheet 1 of 2)

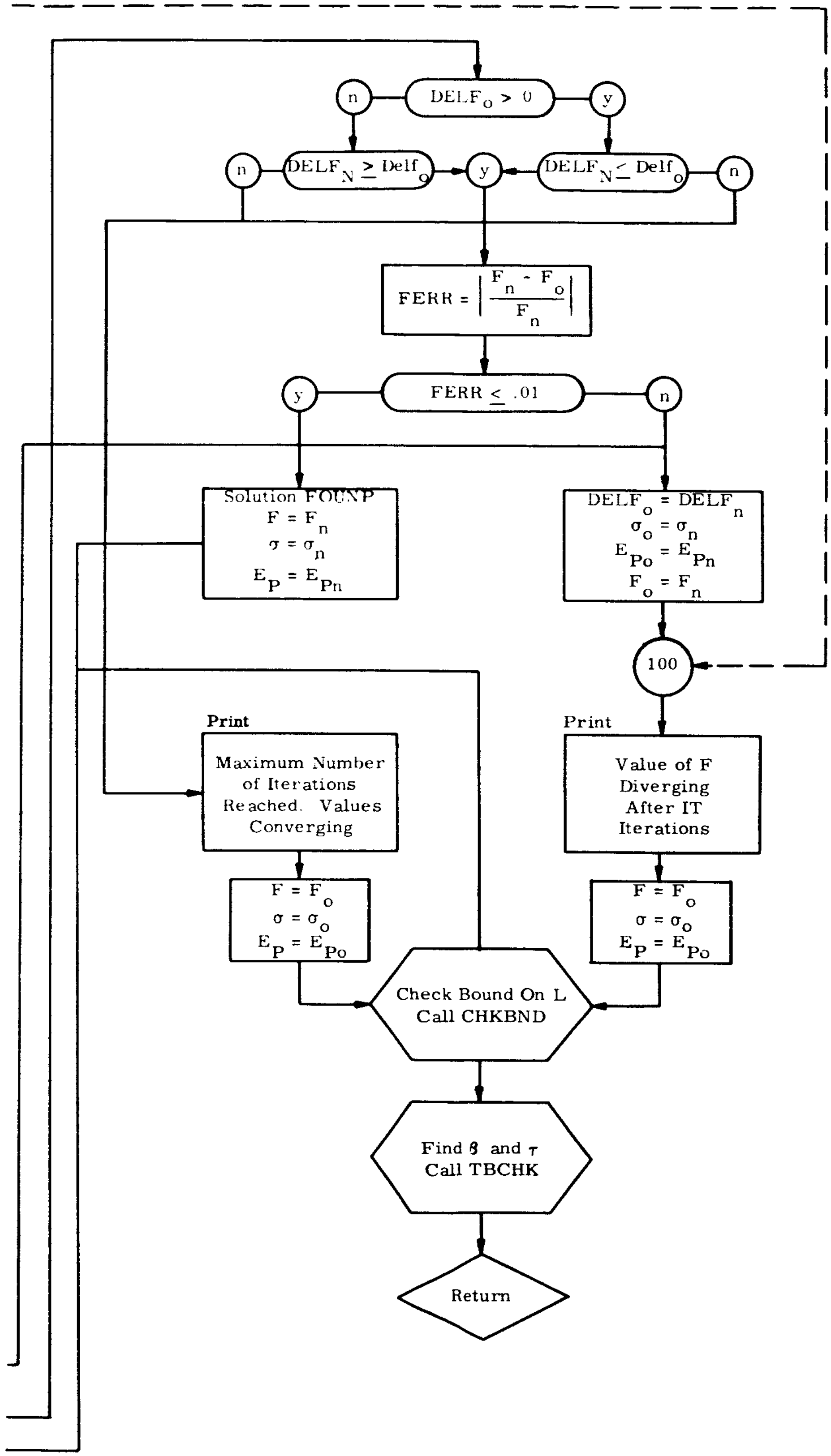

Figure 4-59. LOOP2 Subroutine Flow Chart (Sheet 2 of 2)

Subroutine SIEP

F_x, E_{Po}, σ_x, E_{Px}

$$\sigma_x = F_x \left(\frac{N \times B \times E_{Po}}{L} \right)^{1/2}$$

$$FRAC = 1. + \left(0.3851/\log_{10}\left(\frac{\sigma_o}{\sigma_{0.85}}\right)\right)$$

$$FRAC1 = 1. + \left(0.428\ FRAC \left(\frac{\sigma_x}{\sigma_o}\right)^{FRAC-1}\right)$$

$$FRAC2 = \sigma_x + \left(0.428\,\sigma_o \left(\frac{\sigma_x}{\sigma_o}\right)^{FRAC}\right)$$

$$E_{Px} = EF \times C \left[\sigma_x/(FRAC1 \times FRAC2)\right]^{1/2}$$

Return

Figure 4-60. SIEP Subroutine Flow Chart

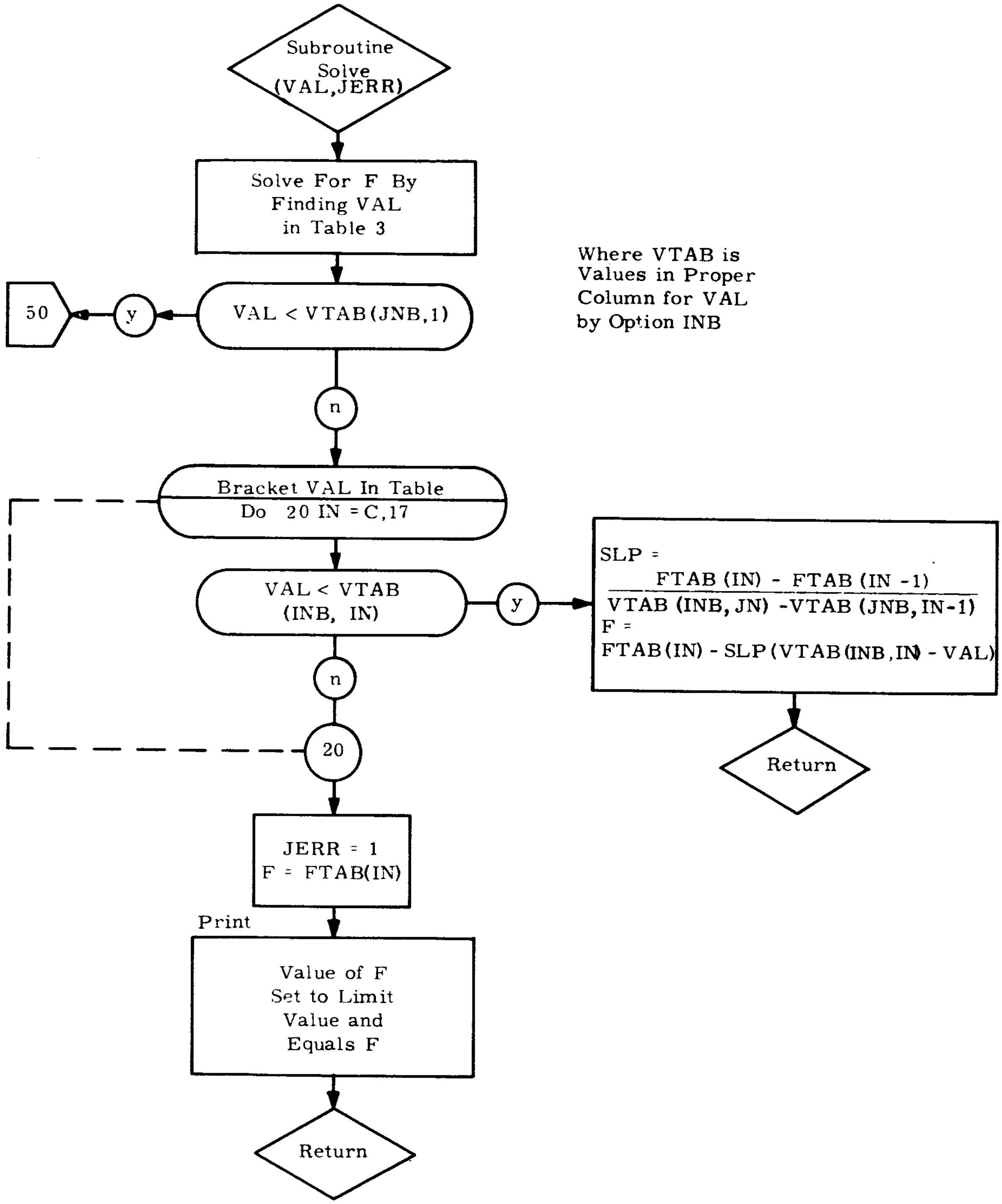

Figure 4-61. SOLVE Subroutine Flow Chart

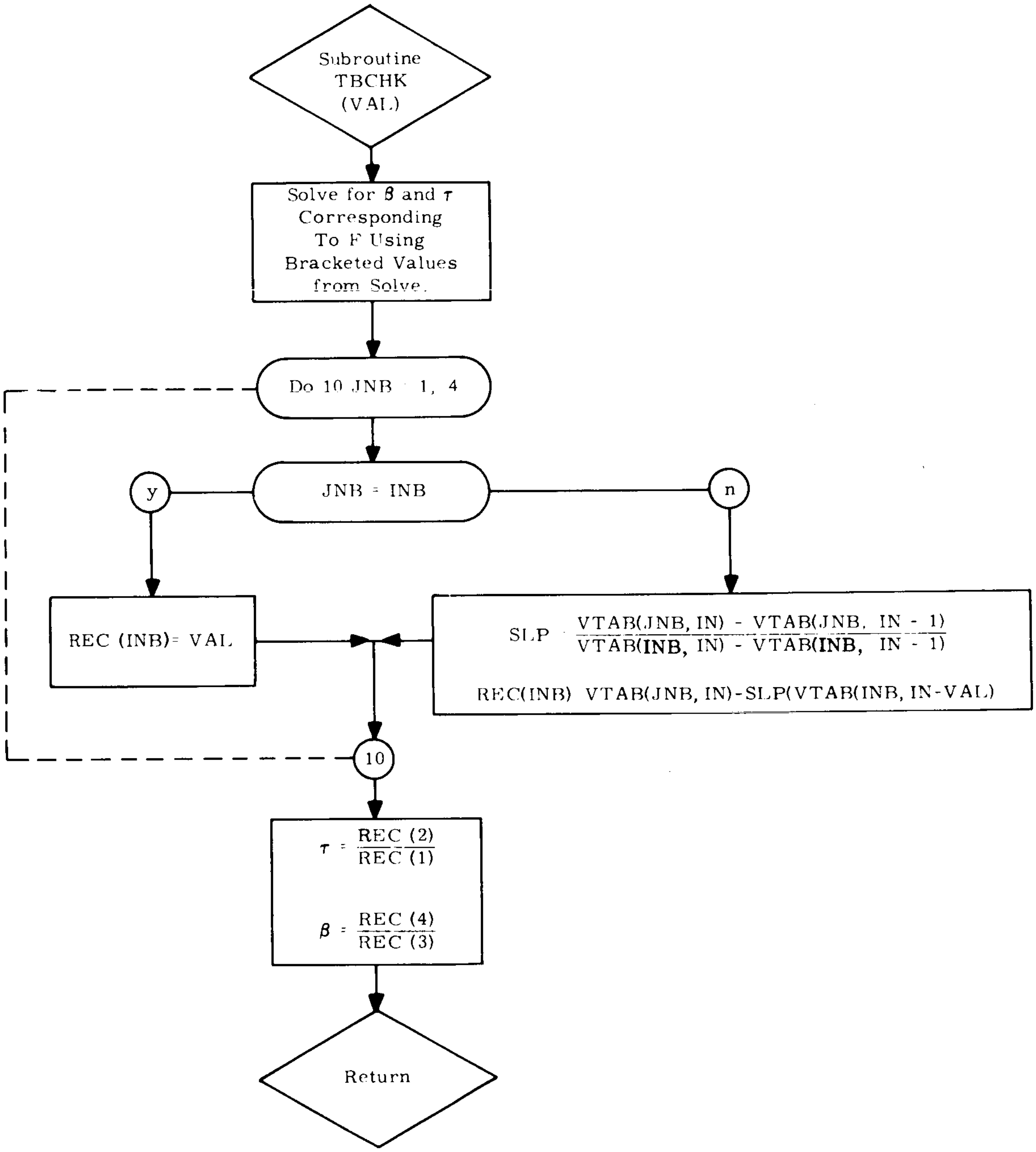

Figure 4-62. TBCHK Subroutine Flow Chart

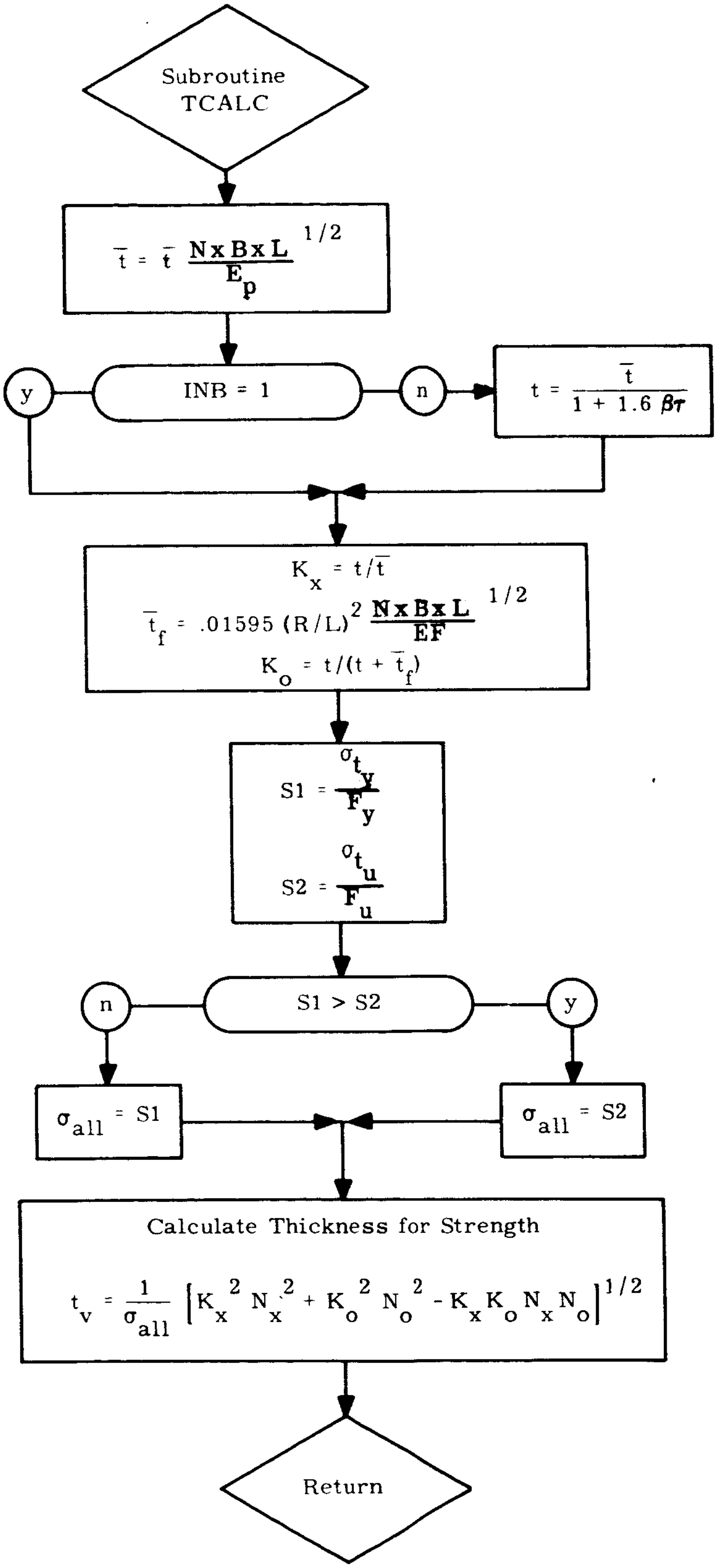

Figure 4-63. TCALC Subroutine Flow Chart

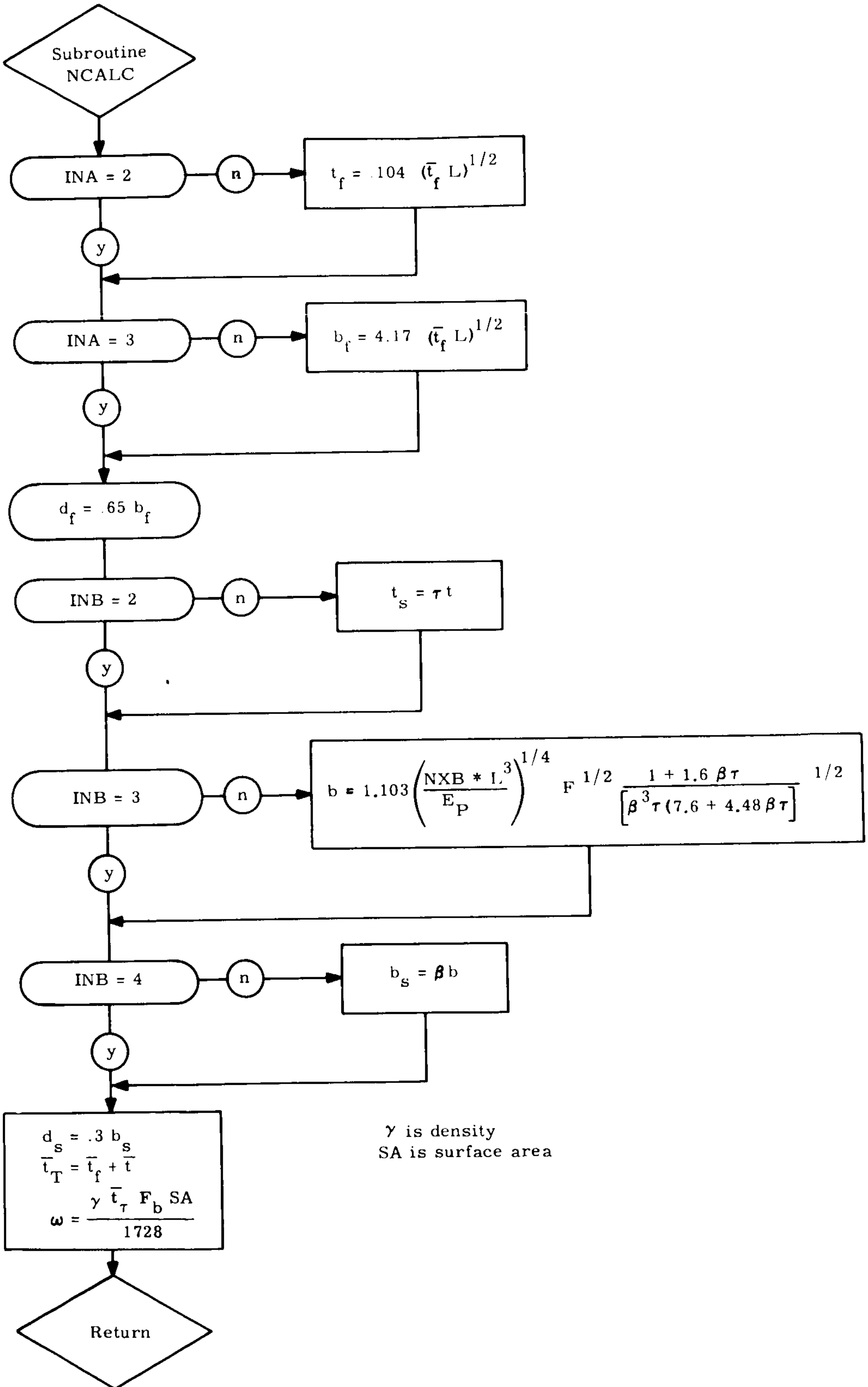

Figure 4-64. NCALC Subroutine Flow Chart

4.13.3.6 SEMAS (4)

The specified value of T is not large enough to satisfy the strength requirement and have an efficient structure for sheet ___. Same as 4.13.3.5 except t has been input.

4.13.3.7 SEMAS (5)

Two parameters fixed for sheet ___. Two of the parameters t, t_s, b, b_s were exceeding limits. Weight is found and calculations abandoned. If input option was specified, omit, and run optimization. If no input option, semi-monocoque is not an efficient structure.

4.13.3.8 SEMAS (6)

The values of B, BS, and TS have been set by limit values. The buckling design is not optimum and should be checked. Same as 4.13.3.7 except three parameters have been fixed.

4.13.3.9 SEMAS (7)

The values of some parameters were set by limit values. Check results for buckling for sheet ___. Same as 4.13.3.8.

4.13.3.10 LOOP1 (1)

Maximum number of iterations reached. Values converging. The values are, EP = ___, SIGMA = ___, L = ___, after ___ iterations. No stabilized value of E_p has been found. Increase number of iterations. The last values calculated will be used and the program continued.

4.13.3.11 LOOP1 (2)

Value of EP diverging after ___ iterations. Values assumed are, EP = ___, SIGMA = ___, L = ___. The last convergent values will be used for further calculations.

4.13.3.12 LOOP2 (1)

Maximum number of iterations reached. Values converging. The values are, F = ___, EP = ___, SIGMA = ___, L = ___ after ___ iterations. No stabilized value of F has been found. The last calculated values will be used. If there is an option, eliminate or increase number of iterations.

4.13.3.13 LOOP2 (2)

Value of F diverging after ___ iterations. Values assumed are, F = ___, EP = ___, SIGMA = ___, L = ___. The last convergent values will be used for further calculations.

4.13.3.14 SOLVE

The value of F set to limit and equals ___. F is out of range of the block data table based on calculated values. This shows that the semi-monocoque construction is not an efficient structure.

4.13.3.15 CHKBND

Value of L set to limit for sheet ___.

4.13.3.16 CKBND1 (1)

Value of B set to limit for sheet ___.

4.13.3.17 CKBND1 (2)

Value of BS set to limit for sheet ___.

4.13.3.18 CKBND1 (3)

Value of TS set to limit for sheet ___. These values are not within the input bounds. Either change bounds or eliminate this construction.

4.13.4 SEMI-MONOCOQUE IMPORTANT NOTES

4.13.4.1 Efficiency Factor F

Input of t_s is not recommended since this value is very sensitive while calculating the efficiency factor F. (See data table for finding F.)

4.13.4.2 Fixed Parameters

When two or more parameters are fixed because of iterations or boundary values, the weight output may be considered inaccurate to ± 5 percent. This is because the boundary values may not have been input as values which correspond to each other.

Table 4-7

Data Table for Finding F when t, t_s, b, or b_s Is Known

Index	F	$b\left(\frac{E_p}{N_x L^3}\right)^{\frac{1}{4}}$	$b_s\left(\frac{E_p}{N_x L^3}\right)^{\frac{1}{4}}$	$t\left(\frac{E_p}{N_x L}\right)^{\frac{1}{2}}$	$t_s\left(\frac{E_p}{N_x L}\right)^{\frac{1}{2}}$
1	0.9500	0.6729	0.7873	0.2945	0.4049
2	0.9611	0.7789	0.7992	0.3503	0.4204
3	0.9504	0.9278	0.8128	0.4381	0.4381
4	0.9292	1.1184	0.8388	0.5491	0.4393
5	0.9239	1.1744	0.8491	0.5795	0.4347
6	0.9136	1.2473	0.8607	0.6174	0.4322
7	0.9022	1.3174	0.8734	0.6561	0.4264
8	0.8862	1.4277	0.8909	0.7057	0.4234
9	0.8628	1.5554	0.9099	0.7652	0.4208
10	0.8272	1.7579	0.9352	0.8480	0.4240
11	0.7733	2.0600	0.9661	0.9668	0.4350
12	0.6921	2.6109	1.0104	1.1581	0.4632
13	0.6000	3.350	1.0950	1.3750	0.5080
14	0.5000	4.500	1.2000	1.6800	0.5970
15	0.4085	6.00	1.3200	2.040	0.7260
16	0.3200	8.00	1.4750	2.510	0.9070
17	0.2050	11.00	1.7060	3.200	1.180

4.14 INTEGRAL RING AND STRINGER STIFFENED CONSTRUCTION SUBPROGRAM

4.14.1 INTRODUCTION

The subprogram finds the construction parameters that yield a minimum weight integral ring and stringer stiffened structure to withstand a given loading. Both cylindrical and conical sections may be analyzed by the same procedure after conical sections are transformed into equivalent cylinders.

The following method of optimization is used. First, the design characteristics have been reduced to four nondimensional ratios of certain design parameters, as described in Appendix N of the user's manual.

A logical range of these nondimensional ratios has been determined by checkout running experience on Saturn V class vehicles, and has been built into the present program. Each range is divided up into five discrete values, which are then used to compute 625 strength-to-weight ratios (for all possible combinations of these discrete values). The resulting strength-to-weight ratios are then arranged in order of descending magnitude, i.e., largest to smallest.

The next step of the procedure is to consider each strength-to-weight ratio for failure via local instability. Tests are performed for skin buckling, rib crippling, panel buckling, and violation of input maximum rib depth. The greatest strength-to-weight ratio is considered first, considering the next lesser one if any test for failure is violated, until a ratio is found which violates none of the tests. This design is then used as a basis for the final design. The final design is adjusted somewhat for strength governed cases, and cases where certain manufacturing limits are violated.

Because loadings vary continuously along the vehicle stations, a continuously varying design would result, except that each structural unit is divided into a number of equal length sheets which are each designed to the maximum loading encountered in their sheet length. The sheet division procedure divides each section into the smallest number of equal length sheets allowable under the input maximum sheet length.

4.14.2 SUBROUTINES USED

4.14.2.1 <u>ISRATS</u>

Subroutine that computes the 125 strength/weight ratios, and arranges them in descending order for testing for failure via local instability.

4.14.2.2 <u>FUNGUS</u>

Subroutine to compute individual values of strength/weight ratios and related parameters for a given value of C1, C2, C3, C4. (Also used by ISRATS as a subroutine.)

4.14.2.3 <u>INTERP</u>

Subroutine to interpolate for the values of temperature-dependent material properties.

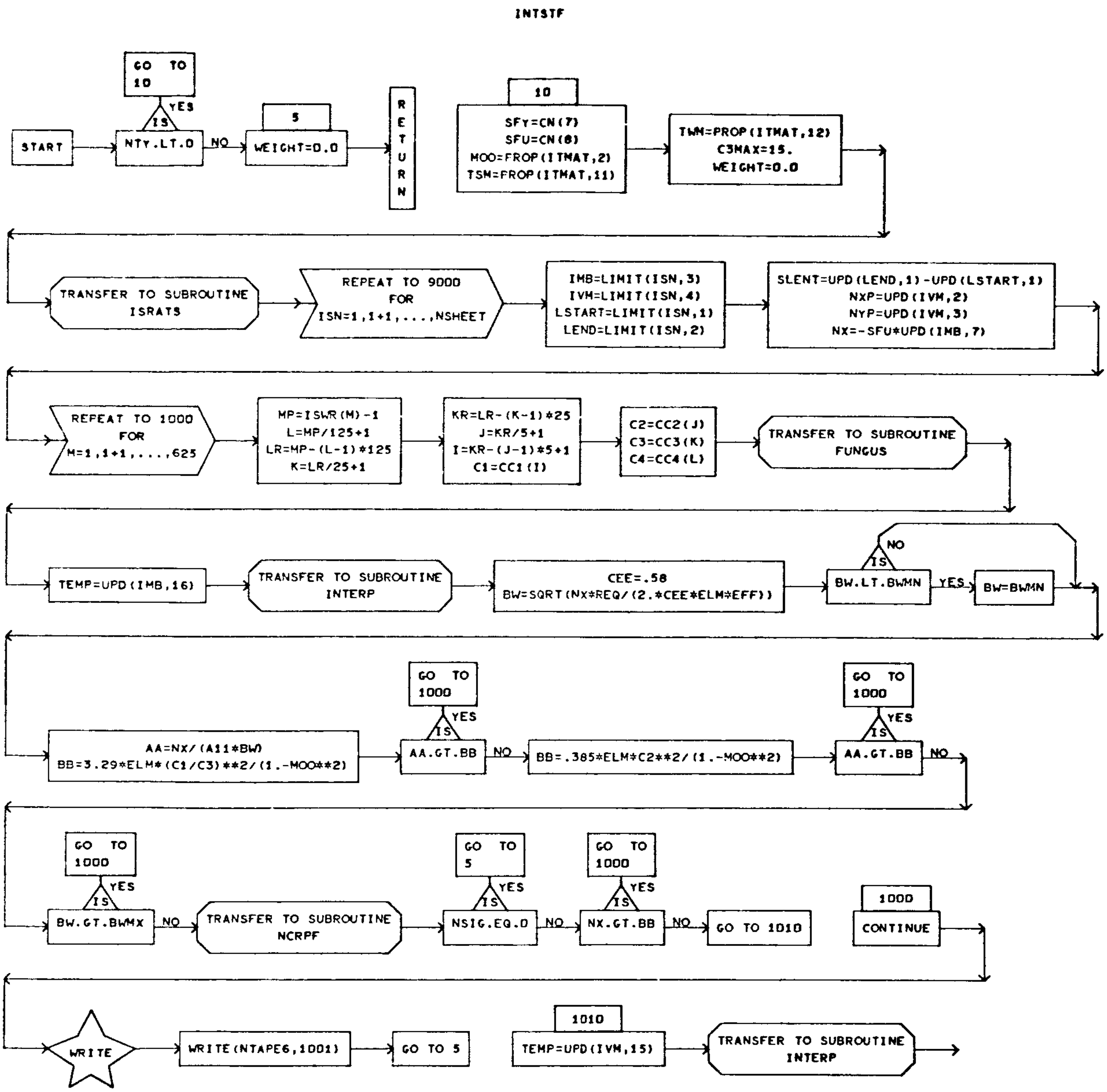

Figure 4-65. INTSTF Flow Chart (Sheet 1 of 4)

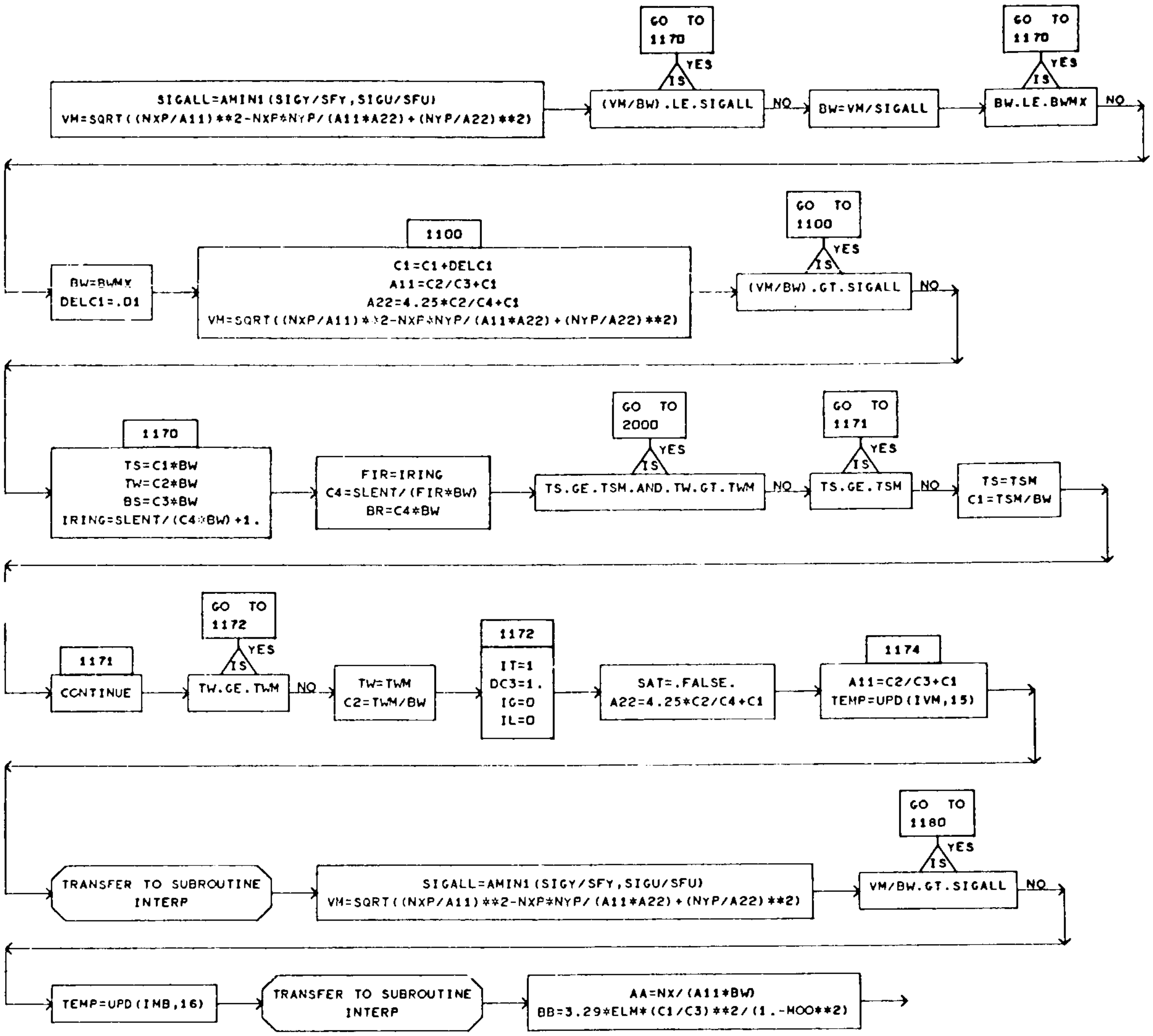

Figure 4-65. INTSTF Flow Chart (Sheet 2 of 4)

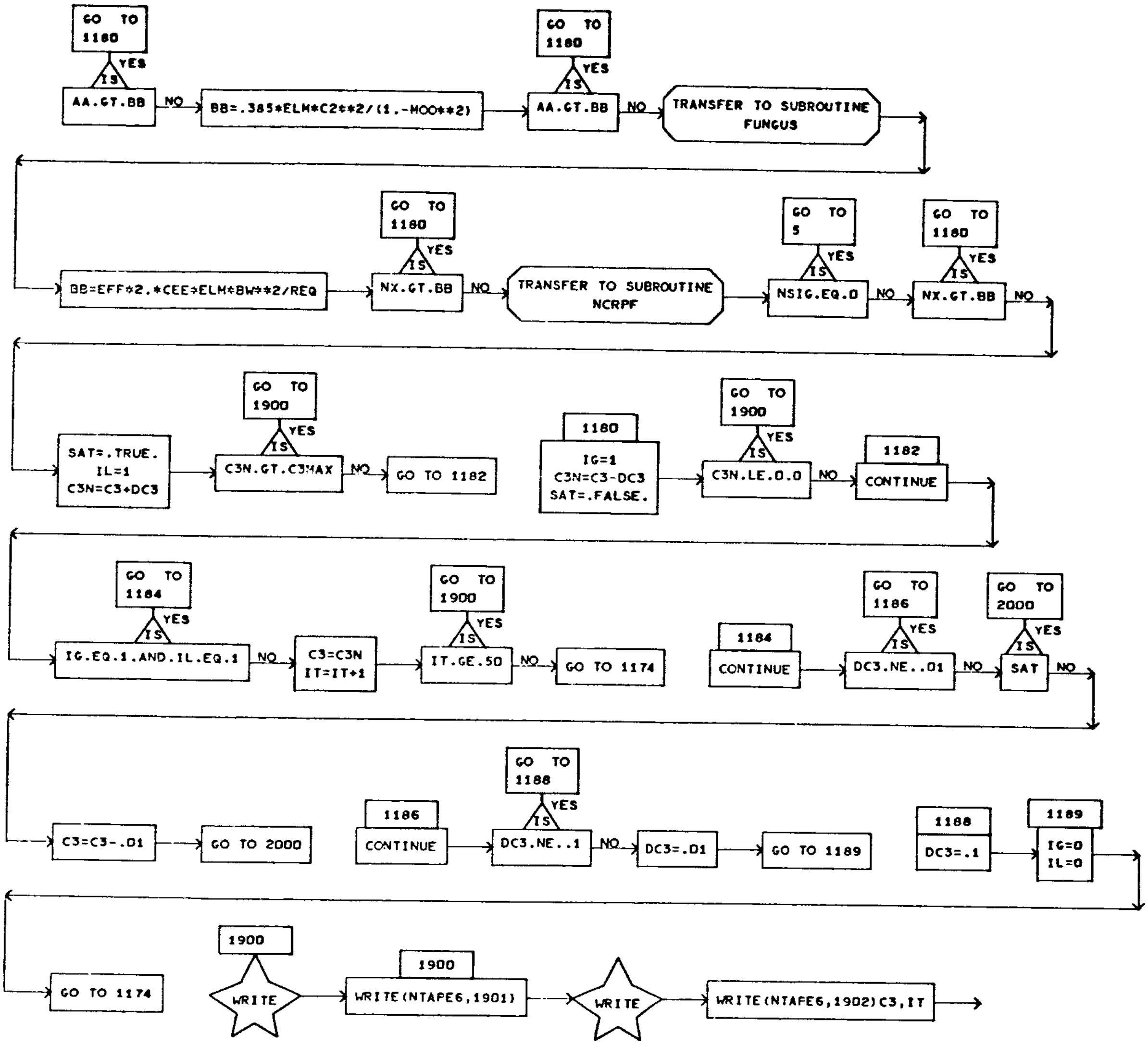

Figure 4-65. INTSTF Flow Chart (Sheet 3 of 4)

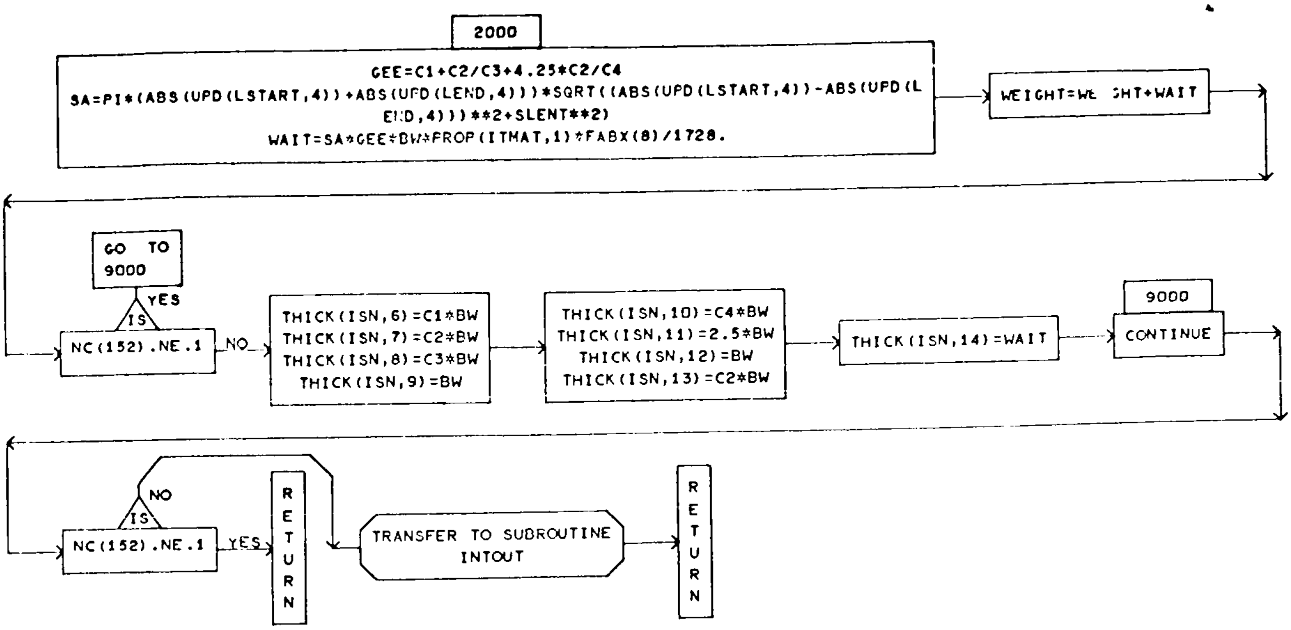

Figure 4-65. INTSTF Flow Chart (Sheet 4 of 4)

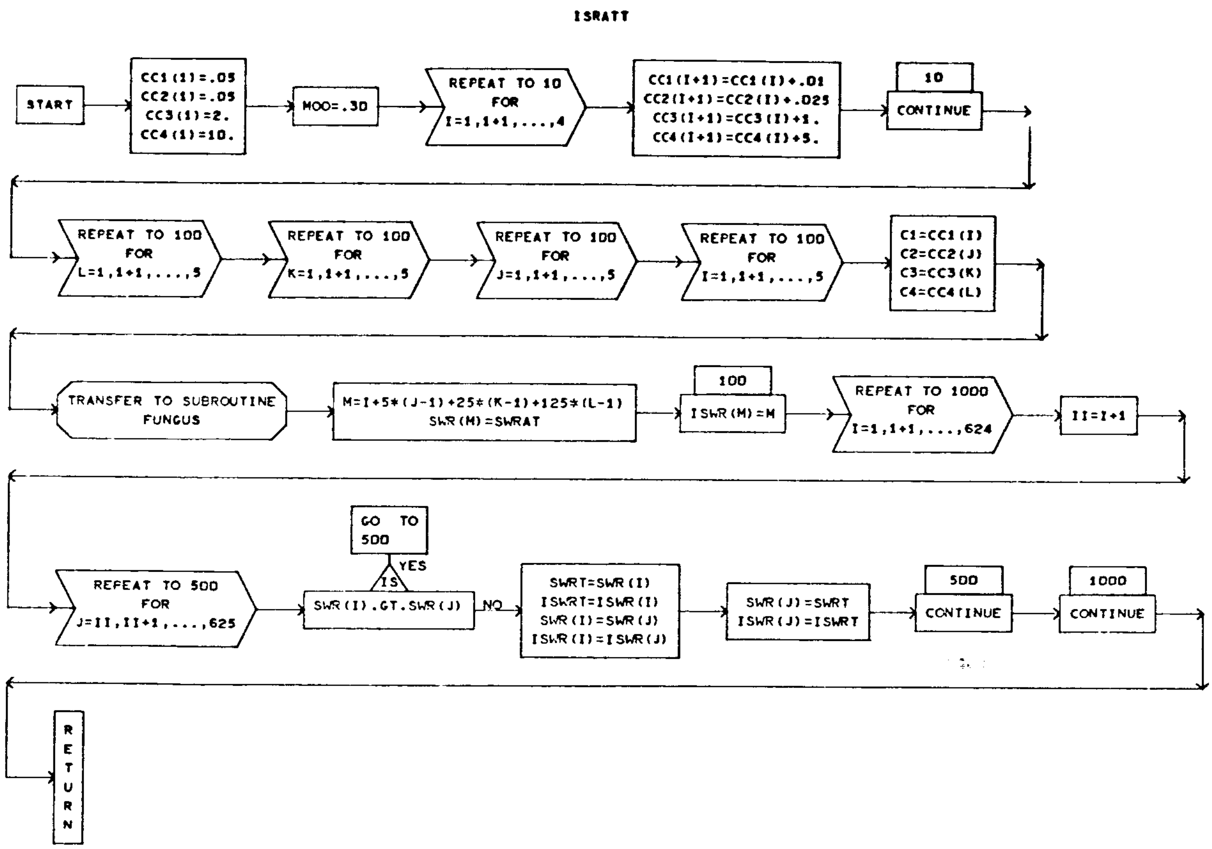

Figure 4-66. ISRATT Subroutine Flow Chart

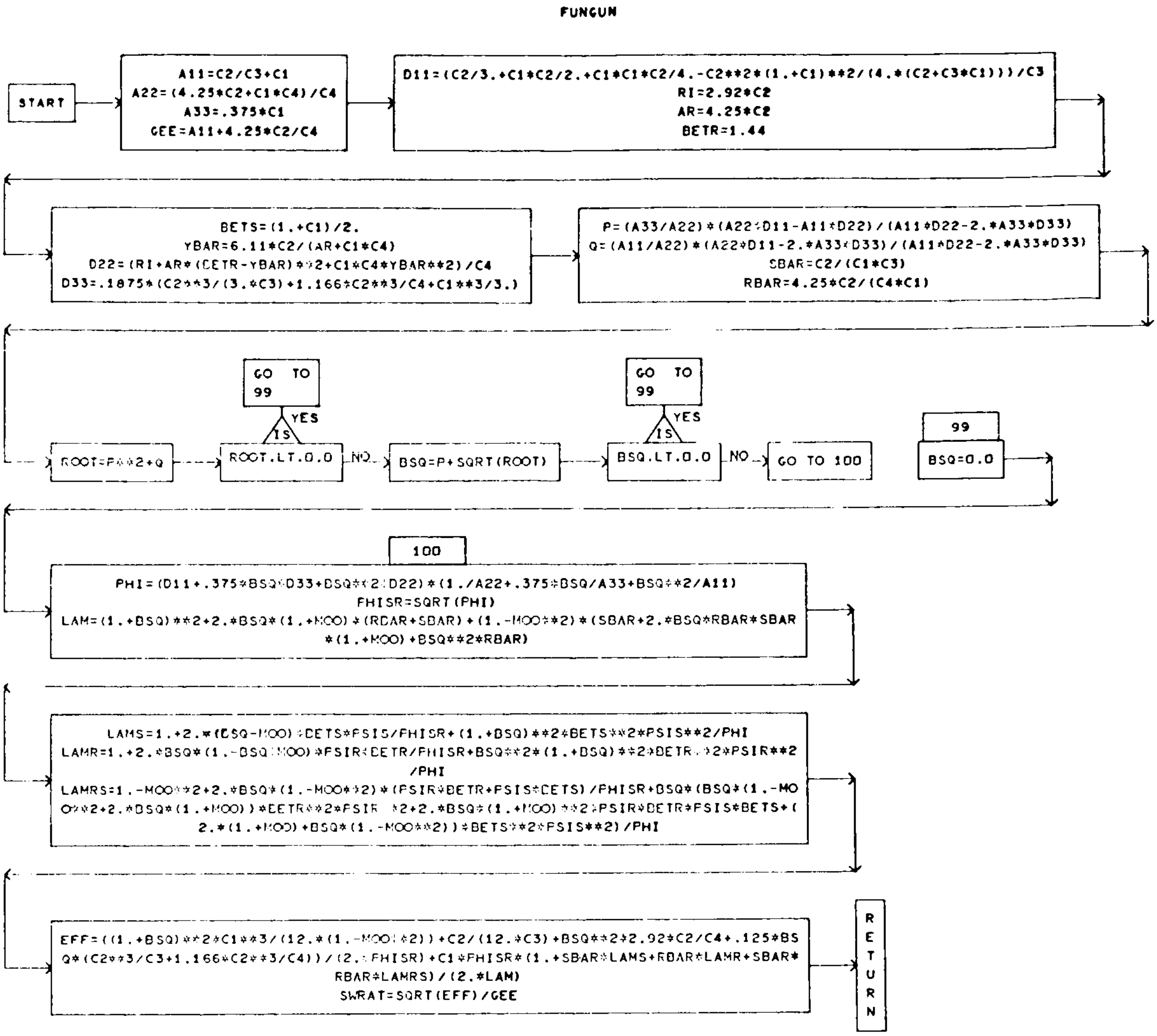

Figure 4-67. FUNGUN Subroutine Flow Chart

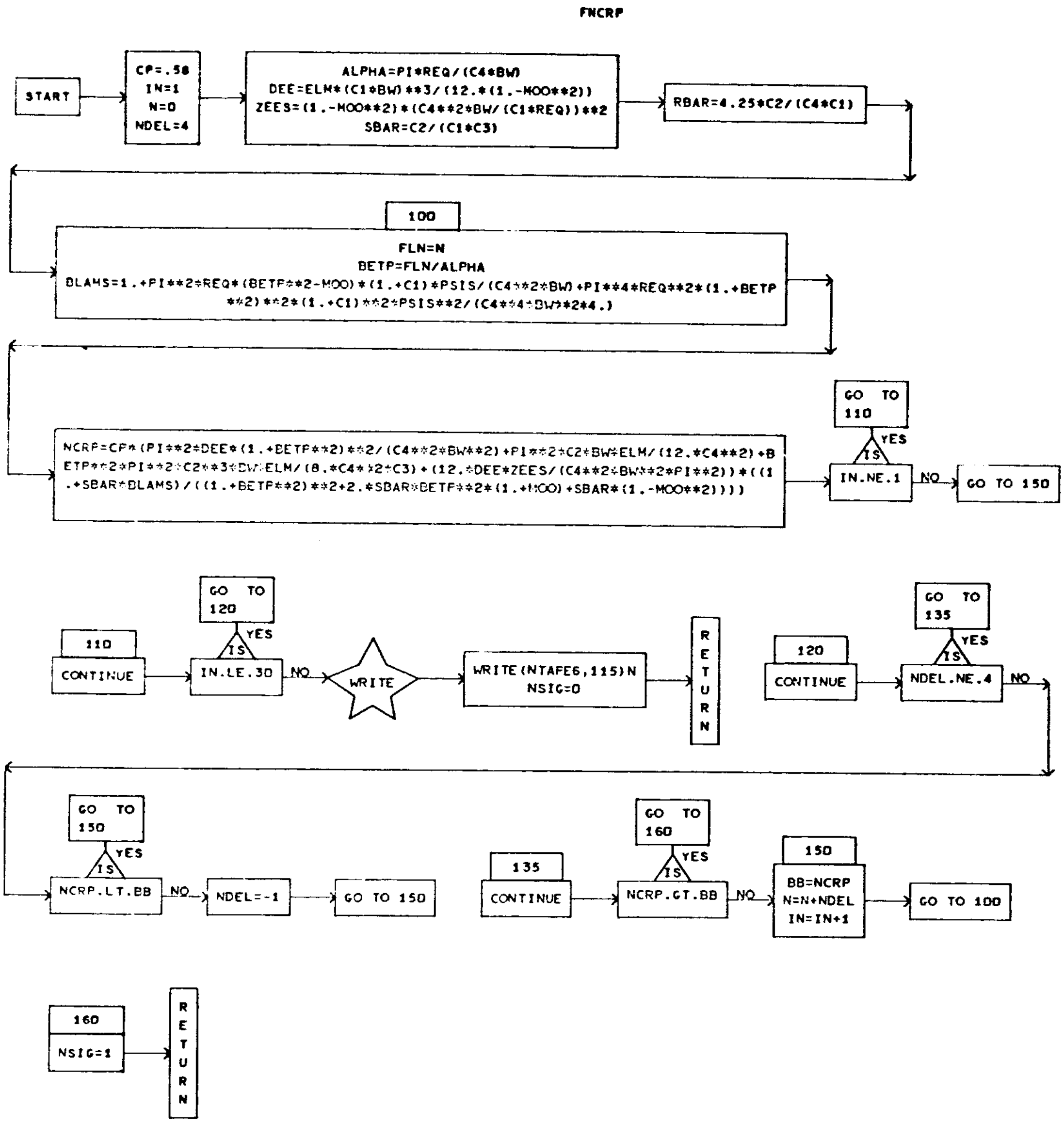

Figure 4-68. FNCRP Subroutine Flow Chart

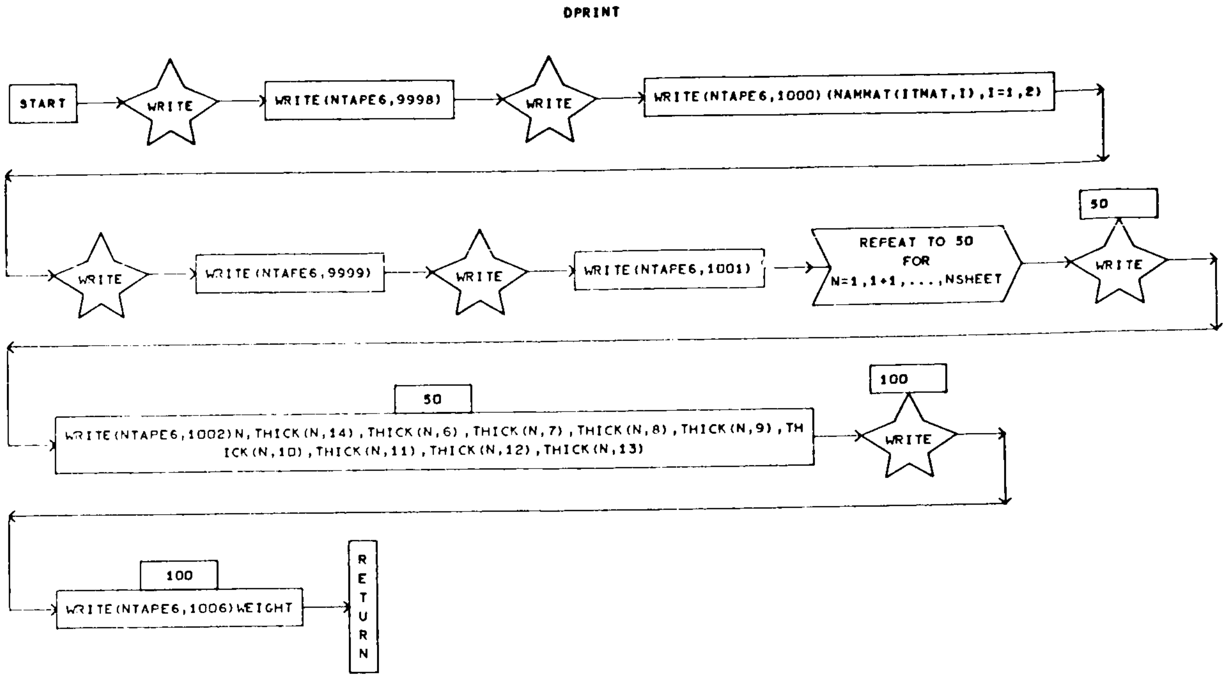

Figure 4-69. DPRINT Subroutine Flow Chart

4.14.2.4 NCRPF

Subroutine to compute panel buckling function via an iterative procedure on buckling modes. Result used to test for local failure via panel buckling.

4.14.2.5 INTOUT

Subroutine to print out details of construction if specified by input signal.

Table 4-8

Definition of Symbols Used In Flow Chart

NTY	Signal that describes type of this section. Section can be handled by this program (i.e., is a cylinder or cone) only if NTY = - 1.
WEIGHT	Final weight returned for this section.
SFY	Yield stress safety factor
CFU	Ultimate stress safety factor
MOO	Poisson's ratio
TSM	Minimum skin thickness allowed
TWM	Minimum stringer thickness allowed
C3MAX	Maximum allowable value of C3
NSHEET	Total number of sheets that this section has been divided into
ISN	The index designating which sheet we are optimizing.
IMB	Index of station where maximum buckling load occurs
IVM	Index of station where maximum membrane load occurs
LSTART	Index of station where this sheet begins
LEND	Index of station where this sheet ends
SLENT	Axial length of this sheet
NXP	Meridional stress corresponding to maximum membrane load in this sheet
NYP	Hoop load corresponding to maximum membrane load in this sheet
NX	Maximum compressive axial load in this sheet (includes safety factor)
M	Index of strength/weight ratio presently being considered
I	Index used in finding value of C1 for strength/weight ratio presently under consideration
J	Index used in finding value of C2
K	Index used in finding value of C3
L	Index used in finding value of C4
TEMP	Temperature input to subroutine interp for finding of temperature-dependent material properties.

Table 4-8

Definition of Symbols Used In Flow Chart (Cont.)

BW	Stringer depth
BWMN	Minimum allowable stringer depth
AA	Variable representing actual value of a load parameter when testing for local instability
BB	Variable representing allowable value of a load parameter when testing for local instability
BWMX	Maximum allowable stringer depth
NSIG	Signal for convergence of panel buckling function
SIGALL	Allowable membrane stress
VM	Variable used to determine if maximum allowable membrane stress has been violated
DELC1	Increment used in increasing C1 to increase skin thickness for strength (membrane load) requirements
A11	Extensional thickness in longitudinal direction
A22	Extensional thickness in circumferential direction
TS	Skin thickness
TW	Stringer thickness
BS	Stringer spacing
IRING	Number of rings for this sheet
FIR	Floating point form of IRING
BR	ing spacing
IT	Iteration counter for C3 increasing iteration.
DC3	Increment on C3 in C3 increasing iteration
IG	Signal used in C3 increasing iteration
IL	Signal used in C3 increasing iteration
SAT	Logical variable used in C3 increasing iteration. Indicates whether C3 is above or below maximum allowable C3 for this configuration
C3N	New value of C3 after local instability has been tested.
GEE	Weight function value for this configuration
SA	Surface area of this sheet
WAIT	Weight of this sheet
NC (152)	Signal for printout of detailed output. NC (152) = 1 ⇒ print detailed output. NC (152) = 0 ⇒ do not print detailed output
THICK (I, J)	where I = 1 to 10, J = 1 to 15, is an array used to store the design specifics of each sheet in the section for output by the printout routine

4.14.3 SPECIAL ATTENTION ITEMS

Note that the ring spacing is optimized for each sheet without regard to any of the other sheets. Running experience has shown that it is usually advantageous to input sheet length greater than any section length of the vehicle to allow ring spacing to be optimized for the structural unit as a whole, and then to check that no ring spacing is greater than the manufacturing maximum sheet length. This prevents short sheet length from interfering with optimum ring spacing for the whole unit (by the fact that all sheet joints have a ring around them).

There are the following error returns. "Skin buckling, rib crippling, maximum rib depth, or panel buckling violated for all values of the strength/weight ratio-weight set to zero." This message is printed if all strength/weight ratios violate the tests for local instability. The ranges of C_1, C_2, C_3, and C_4 considered in computing strength/weight ratios were chosen with great care to cover any stress level that could conceivably occur (refer to the curves in Appendix N of the user's manual), so this error return should not happen. If it does happen, check for mistakes in the stresses input to the subprogram, or change the values of the built-in C_1, C_2, C_3, and C_4 if they need changing to cover a very unusual and strange load configuration.

The routine NCRPF computes the minimum value of the panel buckling function N_{cr}^{p} by an iterative process. In checkout and production running at GE/RSD this function never had converging difficulties. A maximum iteration limit is built in to cover a range of n up to 96, where n is the number of full waves in the circumferential direction. For Saturn class vehicles n is in the range of 10 to 25. In case of this error return check input, or increase the iteration limit if needed.